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Volume 6 DECEMBER, 1936 Number 3

# Journal of Sedimentary Petrology

A Publication of the Society of Economic Paleontologists and Mineralogists
a Division of
The American Association of Petroleum Geologists

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# Journal of Sedimentary Petrology

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 6, NO. 3, PP. 125–142, FIGS. 1, 2, TABLES 1–4, DECEMBER, 1936

# THE SIZE DISTRIBUTION OF MINERALS IN MISSISSIPPI RIVER SANDS

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Louisiana State University

ABSTRACT

Sediment samples collected from the bed of the Mississippi River show a considerable variation in grain size and degree of sorting. A study of pairs of samples, from adjacent points in the River, which differ in one or both of these features, indicates that these variations produce such differences in mineral composition that accurate mineralogical comparison of the samples is not possible on the basis of the usual methods of analysis and comparison. Various comparison methods were therefore tested. The most successful one, which eliminates most of these differences in mineral composition, is recommended for use in any study of sediments involving the detailed mineralogical comparison of a series of samples differing in average grain size or sorting.

Most students of sediments recognize the fact that clastic sediments of identical source and mode of deposition are not necessarily identical in mineral composition, and that differences in composition are frequently related to size of grain. The most obvious example of this principle is the difference in composition between a conglomerate and a shale. However, the fact that a particular type of sediment, sand for example, may show a considerable variation in mineral composition with comparatively small differences in average size of grain, or in degree of sorting, has not been sufficiently emphasized in view of its importance from the standpoint of the interpretation of sediments or of their use for purposes of correlation. Recognition of the presence of such differences in composition, and the use of a method of comparison which will at least partially eliminate them, is almost essential to any study involving the comparison, mineralogically, of a series of sediment samples differing in average grain size or sorting.

References to this subject in the literature are surprisingly few, and most of them deal only with variations in percentages of the accessory or "heavy" minerals of sediments. Mackie (1) has shown that, due to processes of sedimentation, the total percentage of heavy minerals differs in sands of different grain size, and also in the various size grades of a particular sample, tending to be concentrated in its finer grained portion. This principle is well known to all sedimentary petrologists. Mackie, however, did not discuss variations in percentages of the individual heavy minerals in the different size grades of a single sample, though the occurrence of these variations is largely a corollary to the laws governing the distribution of the heavy mineral group as a whole. Actual analyses of the heavy mineral content of various size grades of clastic sediment samples have been made by

several workers (2), and have shown that such variations often are of considerable magnitude. Yet many of these investigators apparently failed to realize that if the percentages of the various heavy minerals differed with size of grain in a single sample, they would also be different in two samples of different average grain size. Sorting as a factor in the distribution of the individual heavy minerals in different samples has also been largely disregarded.

The first analytical treatment of this problem, as far as the writer is aware, is that given by Rubey (3). In this excellent theoretical discussion, Rubey showed that there should be major differences, not only in the percentages of the various heavy minerals in the different size grades of a particular sample, but also in the heavy mineral composition of two sands of identical source, deposited at the same time and distance from the source, but differing in average size of grain, or in sorting, or in both of these features. These differences, he pointed out, may be of such magnitude as to make the sands appear to be quite unrelated, unless a method of comparison is used which will eliminate most of the differences.

Several methods of comparison of samples, designed to obviate these difficulties, have been described. Pettijohn (4) has used a system in which the percentage of each heavy mineral is referred to a standard mineral, i.e., garnet, and the variation of each mineral shown with respect to this standard. Cogen (5) compares the percentage of each heavy mineral to the percentage of the same mineral in a standard "reference sample." Although these methods have their advantages, neither is applicable to all types of problems. The method suggested by Rubey (3) seems to be more logical. It consists in averaging the heavy mineral composition of two size grades from each sample. One of these grades should be the same *actual* size for all samples; the other should be the same *relative* size with respect to the sorting of each sample.

Less attention has been devoted to the light minerals, but, as might be expected, analyses (2. Sabban, Graham, Trowbridge and Shepard, Manger; 6, Martens) have shown that they also vary in percentages in the different size grades of a particular sample. Samples differing in average grain size or in sorting should, therefore, show differences in the composition of both their light and heavy fractions.

This subject has interested the writer for some time and became of paramount importance in a study of the mineral composition of bed material[a] samples from the Mississippi River. Samples collected at intervals of a few miles from Cairo, Ill., to the Gulf of Mexico, are being studied with a view to determining the effect of transportation by the River upon

[a] The term *bed material* is used by the Mississippi River Commission to indicate sediment at rest on the bed of the stream, in contrast to the *bed load* and *suspended load*, which are in motion. Bed material may therefore be considered, in most cases, to be bed load which is temporarily at rest.

the mineral composition of its bed load. If the data secured from such a study are to lead to trustworthy conclusions, it is obvious that differences between samples due to local variations in grain size and sorting must be eliminated, in order that any progressive changes in composition which may be present will not be obscured by local differences. In order to determine the magnitude of such differences, and to develop, if possible, a method of comparison which will eliminate them, a few picked samples were studied in detail.

The first sample studied is a fairly well sorted, medium-grained sand, collected from the bed of the River seven miles below Cairo, Ill. Analyses made of each size grade of this sample showed decided variations in the percentages of both the light and heavy minerals.[b] A search was then made, among the samples available for study, for pairs of samples differing in grain size or sorting, but from adjacent points in the River where there was little possibility of addition of material from extraneous sources between the samples of a pair. Three such pairs were found and the results of their analysis are presented here.

## THE SAMPLES

The samples available for study were collected by the Mississippi River Commission. During August and November of 1932, 531 samples were taken between Cairo, Ill., and just below New Orleans, La. An additional 84 samples were collected between New Orleans and the Gulf during the month of May, 1934. Annotated maps show the localities from which the samples were secured, and the conditions of the banks and depth of the water at the time of sampling. Mechanical analyses and absolute specific gravity determinations of the samples were made by the Soil Mechanics Laboratory of the U. S. Waterways Experiment Station.[c] Study of the mechanical analyses and the annotated maps showed that there are three pairs of samples which differ in grain size or sorting, but are from places in the River where no tributaries enter the River between the collection points of the two samples of a pair, and where the banks were stable at the time of sampling. These are samples M-144 and M-146, near Barfield, Ark.; M-760¼ and M-760½, about 11 miles above the mouth of Old River (lower course of Red River), La.; and M-968½ and M-972¼, at New Orleans, La. The number of each sample represents the mileage, (by river) below Cairo, Ill., at the point where the sample was collected.

Histograms of the mechanical composition of the samples are shown in Figure 1. Sample M-144 is a very

[b] Since the data secured from this sample are more or less duplicated by those secured from the other samples studied, its analysis is not shown.

[c] The mechanical analyses, specific gravity determinations, and other physical constants for these samples are given in "Studies of river bed materials and their movement, with special reference to the Lower Mississippi River," Paper 17 of the U. S. Waterways Experiment Station, Vicksburg, Miss. Analyses of the mineral composition and shape and roundness of the sand samples, and studies of the results of the mechanical analyses, are in progress at Louisiana State University.

poorly sorted pebbly sand, without a marked concentration of material in any particular size grade. M-146 is a fairly well sorted coarse-grained sand, with the maximum amount of material in the 35 mesh grade.[d] The other samples all show fairly good sorting. M-760¼ is a fine-grained sand, with the maximum in the 100 mesh grade; M-760½ is coarser grained, with the maximum in the 48 mesh grade. M-968½ and M-972¼ have maxima in the same grades, respectively, as M-760¼ and M-760½, but are somewhat better sorted.

## METHOD OF STUDY

After drying for five hours at 105° C., each sample was allowed to cool to room temperature and a small portion of the sample cut out with a Jones splitter. The remainder was then placed in a series of nested sieves. These are standard Tyler wire mesh sieves in which the size of the openings increase, from fine to coarse, approximately in the ratio of the square root of two. The nested sieves were then shaken for 20 minutes in a Ro-Tap mechanical shaker. After the sample had thus been separated into size grades, each grade was weighed, and the heavy minerals were then separated in bromoform. After washing and drying the light and heavy separates, the strongly magnetic materials (magnetite and flakes of iron) were removed from the heavy separates with a small horse-shoe magnet, and the weight percentages of the heavy separates and their magnetic portions calculated. The magnetic separates were then examined under a binocular microscope, for, though a double separation of the magnetics was made, some non-magnetic and weakly magnetic grains were usually trapped with the magnetics. The weight percentage of these grains was estimated and subtracted from the calculated weight percentage of the magnetics. Microscope slides were then prepared of both the heavy separates (minus the strongly magnetic materials) and the light separates, and frequency percentages of the minerals determined by counting between 300 and 500 grains as the slide was moved across the field of the microscope by means of a mechanical stage. The light minerals were studied in three separate slides in order to secure accurate percentages. One was mounted in kollolith (N = 1.5354), one stained with malachite green, and the third immersed

[d] The designations and sizes of the grades discussed are as follows:

| Designation of grade | Seive sizes (diameter of openings in mm.). Passed by | Retained on |
|---|---|---|
| 14 mesh | 10 mesh, 1.651 mm. | 14 mesh, 1.168 mm. |
| 20 mesh | 14 mesh, 1.168 mm. | 20 mesh, 0.833 mm. |
| 28 mesh | 20 mesh, 0.833 mm. | 28 mesh, 0.589 mm. |
| 35 mesh | 28 mesh, 0.589 mm. | 35 mesh, 0.417 mm. |
| 48 mesh | 35 mesh, 0.417 mm. | 48 mesh, 0.295 mm. |
| 65 mesh | 48 mesh, 0.295 mm. | 65 mesh, 0.208 mm. |
| 100 mesh | 65 mesh, 0.208 mm. | 100 mesh, 0.147 mm. |
| 150 mesh | 100 mesh, 0.147 mm. | 150 mesh, 0.104 mm. |
| 200 mesh | 150 mesh, 0.104 mm. | 200 mesh, 0.074 mm. |
| <200 mesh | 200 mesh, 0.074 mm. | pan. |

in a liquid of refractive index 1.560 for determination of the more calcic members of the plagioclase feldspar mounted in piperine (N = 1.68). In each case a "microsplit" (7) was used to cut out the material to be mounted

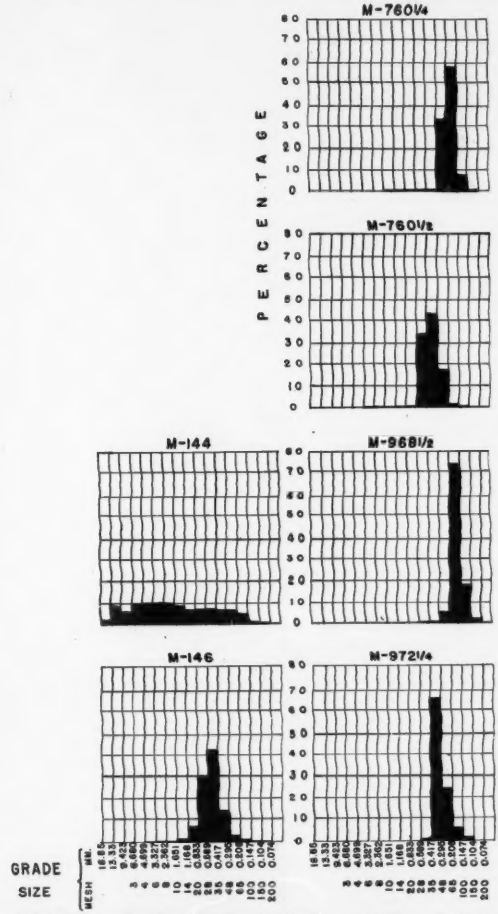


FIG. 1.—Histograms showing the mechanical composition of the samples described. Percentages of the various grades are by weight.

group (labradorite, bytownite, and anorthite).* The heavy minerals were on the slide. The portion of the whole sample, separated out before sieving the remainder, was treated in the same manner as the individual grades. This procedure involved, for the

* This treatment of the light minerals has been described by the writer in "Frequency percentage determinations of detrital quartz and feldspar," *Jour. Sed. Petrol.*, vol. 5(1935), pp. 109-114.

TABLE 1. *Mineral composition of samples M-144 and M-146.*

| Grain size (mesh) | Whole sample | | 20 | | 28 | | 35 | |
|---|---|---|---|---|---|---|---|---|
| Mile No. | 144 | 146 | 144 | 146 | 144 | 146 | 144 | 146 |
| Weight% of each grade (mech. anal.) | | | 6.5 | 6.5 | 6.3 | 29.3 | 6.9 | 42.3 |
| LIGHT SEPARATES (frequency % of minerals) | | | | | | | | |
| 1. Chert and fine-grained quartzite | 5 | 3 | 3 | 7 | 4 | 3 | 3 | 3 |
| 2. Other rock grains | 6 | 7 | 7 | 8 | 8 | 7 | 8 | 10 |
| 3. Quartz | 61 | 68 | 78 | 69 | 68 | 71 | 72 | 70 |
| Feldspars | | | 12 | 16 | | | | |
| 4. Oligoclase and andesine | 13 | 8 | | | 5 | 6 | 10 | 6 |
| 5. Albite | 1 | P | | | R | R | R | R |
| 6. Calcic plagioclase | R | R | | | — | — | — | — |
| 7. Microcline | 6 | 7 | | | 13 | 10 | 4 | 7 |
| 8. Orthoclase and sanidine | 3 | 2 | | | 1 | P | 1 | P |
| 9. Weathered feldspar | 4 | 4 | | | 2 | 2 | 2 | 3 |
| 10. Clay grains | P | P | — | — | — | — | — | — |
| 11. Muscovite | R | R | — | — | — | — | — | — |
| 12. Serpentine and/or chlorite | R | R | — | — | R | — | R | R |
| 13. Calcite | 1 | P | — | — | — | — | — | R |
| 14. Glauconite | R | P | — | — | — | — | — | — |
| 15. Volcanic glass | R | R | — | — | — | — | — | — |
| 16. Carbonaceous matter | R | R | — | — | R | — | — | — |
| HEAVY SEPARATES | | | | | | | | |
| Weight % of heavy separate | 2.3 | 2.2 | | | | | | |
| Weight % of magnetics | 4.3 | 3.6 | | | | | | |
| Frequency % of other minerals on basis of 100% | | | | | | | | |
| 1. Ilmenite | 21 | 11 | | | | | | |
| 2. Leucoxene | 1 | 1 | | | | | | |
| 3. Limonite and hematite | 3 | 4 | | | | | | |
| 4. Pyrite | 2 | 1 | | | | | | |
| 5. Rock grains | 10 | 26 | | | | | | |
| 6. Epidote | 7 | 7 | | | | | | |
| 7. Zoisite | P | P | | | | | | |
| 8. Allanite | P | P | | | | | | |
| 9. Biotite | P | R | | | | | | |
| 10. Olivine | P | R | | | | | | |
| Pyroxenes | | | | | | | | |
| 11. Augite and diopside | 6 | 7 | | | | | | |
| 12. Diallage | 1 | P | | | | | | |
| 13. Brown pyroxene | 2 | 3 | | | | | | |
| 14. Hypersthene | 1 | 2 | | | | | | |
| Amphiboles | | | | | | | | |
| 15. Common hornblende | 5 | 3 | | | | | | |
| 16. Blue-green hornblende | 4 | 3 | | | | | | |
| 17. Basaltic hornblende | P | P | | | | | | |
| 18. Actinolite and tremolite | 3 | 3 | | | | | | |
| Accessories: | | | | | | | | |
| 19. Apatite | P | P | | | | | | |
| 20. Zircon | 4 | P | | | | | | |
| 21. Titanite | 1 | P | | | | | | |
| 22. Rutile | P | R | | | | | | |
| 23. Monazite | 1 | R | | | | | | |
| 24. Staurolite | P | P | | | | | | |
| 25. Andalusite | P | — | | | | | | |
| 26. Sillimanite | 1 | P | | | | | | |
| 27. Kyanite | P | R | | | | | | |
| 28. Chloritoid | R | R | | | | | | |
| 29. Tourmaline (a) | P | P | | | | | | |
| 30. Tourmaline (b) | R | R | | | | | | |
| 31. Tourmaline (c) | R | R | | | | | | |
| 32. Garnet (a) | 11 | 12 | | | | | | |
| 33. Garnet (b) | P | P | | | | | | |
| 34. Garnet (c) | P | 4 | | | | | | |
| 35. Dolomite and siderite | 10 | 10 | | | | | | |
| 36. Collophane | 1 | P | | | | | | |
| Ratio: Quartz to quartz plus total feldspar | 69 | 76 | 87 | 81 | 76 | 80 | 81 | 81 |
| Total pyroxenes | 10.8 | 12.3 | | | | | | |
| Total amphiboles | 12.2 | 8.5 | | | | | | |
| Total accessories | 7.0 | 0.8 | | | | | | |

P = Present in amounts less than one per cent but fairly common.
R = Rare.

| 48 | | 65 | | 100 | | 150 | | 200 | | <200 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 144 | 146 | 144 | 146 | 144 | 146 | 144 | 146 | 144 | 146 | 144 | 146 |
| 6.2 | 13.6 | 6.4 | 3.1 | 4.3 | 1.3 | 0.8 | 0.7 | 0.2 | 0.1 | 0.1 | 0.1 |
| 2 | 4 | 6 | 3 | 7 | 13 | 8 | 9 | 5 | 5 | 7 | 6 |
| 3 | 4 | 4 | 6 | 9 | 6 | 7 | 8 | 6 | 8 | 3 | 4 |
| 70 | 73 | 70 | 69 | 60 | 58 | 54 | 45 | 60 | 51 | 52 | 60 |
| 11 | 7 | 7 | 14 | 9 | 10 | 14 | 18 | 13 | 17 | 11 | 6 |
| P | P | P | R | P | 1 | P | 1 | P | 2 | 1 | 2 |
| — | R | R | R | P | P | P | P | P | P | P | P |
| 7 | 8 | 8 | 5 | 8 | 5 | 5 | 6 | 6 | 4 | 5 | 4 |
| 1 | 1 | 1 | P | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| 4 | 3 | 3 | 3 | 4 | 4 | 8 | 7 | 4 | 6 | 5 | 3 |
| — | — | — | — | R | R | P | 1 | 3 | 3 | 4 | 3 |
| — | — | — | R | R | R | R | P | — | — | R | — |
| — | — | R | R | P | P | P | P | P | 1 | 1 | 1 |
| — | — | — | — | R | R | P | 1 | 1 | P | 6 | 6 |
| — | — | — | — | — | R | P | R | P | R | P | P |
| — | — | — | R | R | P | R | R | R | R | R | 1 |
| — | — | R | — | R | R | P | P | P | P | 1 | 1 |
| | | 2.5 | 7.4 | 2.2 | 9.0 | 11.7 | 6.9 | 21.8 | 11.1 | 22.3 | 16.3 |
| | | 5.7 | 7.9 | 6.7 | 28.6 | 12.6 | 11.8 | 17.6 | 12.1 | 20.0 | 10.1 |
| | | 10 | 11 | 8 | 16 | 21 | 17 | 38 | 8 | 22 | 8 |
| | | 2 | P | 3 | P | 3 | 3 | 2 | 3 | 1 | 1 |
| | | 3 | 5 | 2 | 3 | 3 | 5 | 3 | 3 | 6 | 5 |
| | | — | — | R | P | P | 2 | 2 | 6 | 16 | 49 |
| | | 34 | 26 | 10 | 10 | 3 | 3 | 2 | 2 | 2 | 1 |
| | | 7 | 4 | 5 | 5 | 6 | 6 | 6 | 3 | 5 | 4 |
| | | — | R | R | — | P | P | P | R | P | P |
| | | — | — | — | — | R | — | R | R | R | R |
| | | P | — | P | P | R | P | — | R | — | — |
| | | P | P | R | P | P | R | R | R | R | R |
| | | 7 | 7 | 14 | 10 | 10 | 10 | 3 | 6 | 4 | 2 |
| | | 2 | 2 | 3 | 2 | 1 | 2 | P | P | P | P |
| | | 5 | 6 | 2 | 3 | P | P | P | P | P | R |
| | | 2 | P | 1 | 2 | P | 2 | P | P | 1 | R |
| | | 4 | 4 | 12 | 8 | 6 | 5 | 3 | 5 | 3 | 2 |
| | | 2 | 2 | 3 | 3 | 2 | P | 1 | 2 | 2 | P |
| | | P | — | P | — | P | P | P | P | P | P |
| | | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 2 | 2 | P |
| | | — | — | 1 | P | 1 | 2 | 1 | 1 | 3 | P |
| | | — | — | P | 1 | 3 | 3 | 7 | 1 | 9 | 3 |
| | | — | R | 1 | P | 2 | 1 | 1 | P | 2 | P |
| | | — | — | R | R | P | P | R | R | P | R |
| | | — | — | R | P | P | P | R | P | P | R |
| | | P | 1 | 1 | R | P | R | R | — | R | — |
| | | — | R | R | P | — | R | P | R | — | — |
| | | P | — | 1 | R | R | R | — | — | R | — |
| | | P | P | P | R | P | P | — | R | P | — |
| | | R | P | R | — | — | P | — | R | — | R |
| | | — | R | P | — | — | P | P | R | P | R |
| | | — | — | R | — | — | R | P | R | P | R |
| | | 8 | 17 | 11 | 16 | 12 | 8 | 6 | 2 | 3 | 1 |
| | | 1 | 1 | P | P | P | P | P | R | P | — |
| | | P | 2 | 1 | 2 | P | 1 | P | R | P | R |
| | | 7 | 5 | 16 | 11 | 21 | 24 | 20 | 54 | 16 | 20 |
| | | P | P | P | 1 | P | 1 | R | R | P | — |
| 75 | 79 | 79 | 76 | 72 | 73 | 64 | 56 | 70 | 62 | 68 | 78 |
| | | 15.6 | 15.5 | 19.8 | 16.7 | 11.8 | 14.6 | 3.6 | 7.0 | 5.7 | 2.8 |
| | | 9.5 | 9.4 | 16.3 | 13.8 | 10.7 | 6.9 | 5.6 | 8.4 | 7.2 | 3.0 |
| | | 0.0 | 0.0 | 2.2 | 1.7 | 5.9 | 6.2 | 9.6 | 2.6 | 14.3 | 4.7 |

TABLE 2. *Mineral composition of samples M-760¼ and M-760½.*

| Grain size (mesh) | Whole sample | | 20 | | 28 | | 35 | |
|---|---|---|---|---|---|---|---|---|
| Mile no. | 760¼ | 760½ | 760¼ | 760½ | 760¼ | 760½ | 760¼ | 760½ |
| Weight % of each grade (mech. anal.) | | | 0.1 | 0.4 | 0.1 | 3.4 | 0.1 | 34.0 |
| LIGHT SEPARATES (frequency % of minerals) | | | | | | | | |
| 1. Chert and fine-grained quartzite | 7 | 5 | | 6 | | 7 | | 5 |
| 2. Other rock grains | 8 | 8 | | 5 | | 3 | | 2 |
| 3. Quartz | 59 | 69 | | 70 | | 76 | | 78 |
| Feldspars | | | | 19 | | | | |
| 4. Oligoclase and andesine | 16 | 8 | | | | 6 | | 3 |
| 5. Albite | P | P | | | | R | | R |
| 6. Calcic plagioclase | P | — | | | | — | | — |
| 7. Microcline | 4 | 6 | | | | 4 | | 8 |
| 8. Orthoclase and sanidine | 1 | 1 | | | | P | | 1 |
| 9. Weathered feldspar | 4 | 3 | | | | 3 | | 3 |
| 10. Clay grains | P | P | | — | | — | | — |
| 11. Muscovite | P | — | | — | | — | | — |
| 12. Serpentine and/or chlorite | P | P | | — | | — | | — |
| 13. Calcite | P | — | | — | | — | | — |
| 14. Glauconite | R | R | | — | | — | | — |
| 15. Volcanic glass | R | — | | — | | — | | — |
| 16. Carbonaceous matter | R | — | | — | | — | | — |
| HEAVY SEPARATES | | | | | | | | |
| Weight % of heavy separate | 2.1 | 1.3 | | | | | | |
| Weight % of magnetics | 8.0 | 4.5 | | | | | | |
| Frequency % of other minerals on basis of 100% | | | | | | | | |
| 1. Ilmenite | 13 | 11 | | | | | | |
| 2. Leucoxene | 4 | 5 | | | | | | |
| 3. Limonite and hematite | 2 | 8 | | | | | | |
| 4. Pyrite | 1 | 9 | | | | | | |
| 5. Rock grains | 7 | 19 | | | | | | |
| 6. Epidote | 5 | 5 | | | | | | |
| 7. Zoisite | P | P | | | | | | |
| 8. Biotite | P | P | | | | | | |
| 9. Olivine | P | P | | | | | | |
| Pyroxenes | | | | | | | | |
| 10. Augite and diopside | 7 | 10 | | | | | | |
| 11. Diallage | P | 1 | | | | | | |
| 12. Brown pyroxene | P | 3 | | | | | | |
| 13. Hypersthene | P | P | | | | | | |
| Amphiboles | | | | | | | | |
| 14. Common hornblende | 10 | 7 | | | | | | |
| 15. Blue-green hornblende | 2 | 1 | | | | | | |
| 16. Basaltic hornblende | P | P | | | | | | |
| 17. Actinolite and tremolite | 2 | 1 | | | | | | |
| Accessories | | | | | | | | |
| 18. Apatite | 1 | P | | | | | | |
| 19. Zircon | 1 | 1 | | | | | | |
| 20. Titanite | P | P | | | | | | |
| 21. Rutile | P | P | | | | | | |
| 22. Monazite | P | R | | | | | | |
| 23. Staurolite | P | P | | | | | | |
| 24. Andalusite | P | R | | | | | | |
| 25. Sillimanite | P | P | | | | | | |
| 26. Kyanite | P | P | | | | | | |
| 27. Chloritoid | P | P | | | | | | |
| 28. Tourmaline (a) | P | P | | | | | | |
| 29. Tourmaline (b) | P | R | | | | | | |
| 30. Tourmaline (c) | — | R | | | | | | |
| 31. Garnet (a) | 6 | 5 | | | | | | |
| 32. Garnet (b) | P | P | | | | | | |
| 33. Garnet (c) | P | 1 | | | | | | |
| 34. Dolomite and siderite | 34 | 7 | | | | | | |
| 35. Collophane | P | 2 | | | | | | |
| Ratio: Quartz to quartz plus total feldspar | 69 | 78 | | 89 | | 85 | | 84 |
| Total pyroxenes | 8.0 | 14.9 | | | | | | |
| Total amphiboles | 14.0 | 9.2 | | | | | | |
| Total accessories | 3.0 | 2.3 | | | | | | |

P = Present in amounts less than one per cent but fairly common.
R = Rare.

| 48 | | 65 | | 100 | | 150 | | 200 | | <200 | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 760¼ | 760½ | 760¼ | 760½ | 760¼ | 760½ | 760¼ | 760½ | 760¼ | 760½ | 760¼ | 760½ |
| 0.5 | 43.2 | 33.1 | 17.5 | 57.8 | 1.3 | 7.6 | 0.1 | 0.6 | 0.1 | 0.1 | Trace |
| 5 | 5 | 6 | 9 | 6 | 6 | 4 | 7 | 6 | 6 | 4 | 3 |
| 21 | 4 | 15 | 7 | 10 | 10 | 8 | 9 | 9 | 6 | 7 | 3 |
| 63 | 74 | 57 | 72 | 61 | 65 | 56 | 50 | 54 | 50 | 34 | 51 |
| 4 | 5 | 7 | 2 | 7 | 7 | 17 | 19 | 12 | 18 | 11 | 20 |
| P | P | P | R | P | P | P | P | P | P | P | P |
| — | — | R | R | P | P | P | P | P | P | P | P |
| 4 | 8 | 7 | 5 | 5 | 4 | 4 | 4 | 3 | 5 | 3 | 4 |
| 1 | P | 2 | 1 | 2 | 2 | 1 | 2 | 2 | 3 | 2 | 1 |
| 2 | 4 | 6 | 4 | 7 | 6 | 8 | 6 | 8 | 8 | 6 | 7 |
| — | — | — | — | P | P | P | 1 | 3 | 2 | 10 | 2 |
| R | — | P | — | P | R | P | R | P | R | R | R |
| R | — | P | — | P | R | P | P | 1 | 3 | 1 | P |
| — | — | — | — | P | R | P | P | P | R | 20 | 7 |
| — | — | — | — | P | R | P | R | R | R | P | R |
| — | — | R | — | R | R | R | R | R | R | P | R |
| — | — | P | — | P | — | R | R | R | P | R | 1 |
| | 0.8 | 0.6 | 1.5 | 1.4 | 10.0 | 9.2 | 16.0 | 32.0 | 28.7 | 32.0 | 20.1 |
| | 1.0 | 0.4 | 1.2 | 0.4 | 12.0 | 8.0 | 36.0 | 30.3 | 25.4 | 32.0 | 46.4 |
| | 2 | 4 | 5 | 5 | 22 | 13 | 29 | 36 | 16 | 12 | 3 |
| | 2 | 4 | 1 | 6 | 3 | 4 | 4 | 4 | 9 | 2 | P |
| | P | 3 | 2 | 3 | 2 | 4 | 11 | 4 | 17 | 12 | 15 |
| | P | P | R | P | R | P | 4 | 1 | 4 | 28 | 51 |
| | 71 | 54 | 40 | 19 | 7 | 6 | 4 | 1 | 3 | P | 2 |
| | 2 | 1 | 3 | 5 | 4 | 10 | 4 | 5 | 4 | 2 | 1 |
| | — | — | — | P | P | P | R | R | R | R | — |
| | — | 3 | P | P | R | P | P | P | R | P | R |
| | — | P | P | P | P | P | P | — | | — | R |
| | 5 | 4 | 11 | 7 | 10 | 5 | 4 | 5 | 3 | 3 | 2 |
| | P | 1 | 2 | P | 2 | 3 | P | 1 | P | P | P |
| | 5 | 1 | 3 | 1 | 3 | P | 2 | P | 2 | P | P |
| | P | P | 1 | 2 | 1 | 1 | P | P | P | P | P |
| | 3 | 2 | 5 | 9 | 9 | 14 | 5 | 5 | 3 | 2 | 1 |
| | 4 | 2 | 3 | 4 | 4 | 3 | 3 | 1 | 1 | 1 | P |
| | — | P | — | P | R | P | P | P | P | P | P |
| | 2 | P | 4 | 2 | 3 | 5 | 2 | 2 | 2 | P | P |
| | — | P | P | 1 | P | 2 | P | 1 | 1 | 1 | P |
| | — | R | P | R | 1 | P | 2 | 5 | 2 | 5 | P |
| | — | — | — | P | 1 | R | P | 2 | P | 1 | P |
| | — | — | — | P | — | P | P | 1 | P | P | P |
| | — | — | — | P | R | R | R | R | P | R | R |
| | R | — | P | P | 1 | P | R | P | — | — | — |
| | — | — | — | P | — | P | P | — | — | R | — |
| | R | P | — | P | P | P | R | R | R | — | R |
| | — | — | — | P | R | P | P | — | — | R | — |
| | — | — | — | P | — | P | P | P | P | P | P |
| | — | — | — | P | R | P | P | P | P | P | P |
| | 1 | — | — | — | — | 6 | 4 | 6 | 1 | 2 | P |
| | R | — | — | P | R | P | P | P | P | P | R |
| | R | — | — | P | 15 | P | 1 | 1 | P | P | R |
| | 1 | P | P | P | 2 | P | 1 | P | P | P | P |
| | P | — | P | 2 | 2 | P | 17 | 17 | 29 | 27 | 23 |
| | P | 15 | 8 | 28 | 6 | 19 | R | P | P | P | — |
| 85 | 81 | 72 | 86 | 74 | 77 | 65 | 62 | 68 | 60 | 60 | 61 |
| | 11.1 | 6.3 | 17.0 | 10.6 | 15.0 | 9.6 | 7.1 | 6.9 | 5.7 | 3.6 | 1.7 |
| | 8.8 | 5.0 | 11.8 | 15.2 | 16.2 | 22.7 | 9.8 | 8.1 | 6.2 | 3.4 | 1.1 |
| | 0.0 | 0.3 | 0.6 | 1.6 | 2.4 | 2.6 | 2.8 | 9.3 | 3.2 | 7.5 | 0.6 |

TABLE 3. *Mineral composition of samples M-968½ and M-972½.*

| Grain size (mesh) | 35 | | 48 | | 65 | | 100 | | 150 | | 200 | | <200 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mile no. | 968½ | 972½ | 968½ | 972½ | 968½ | 972½ | 968½ | 972½ | 968½ | 972½ | 968½ | 972½ | 968½ | 972½ |
| Weight % of each grade (mech. anal.) | 0.1 | 1.6 | 0.1 | 66.1 | 4.9 | 24.6 | 74.0 | 5.4 | 18.5 | 2.2 | 2.0 | trace | 0.5 | trace |
| LIGHT SEPARATES (frequency % of minerals) | | | | | | | | | | | | | | |
| 1. Chert and fine-grained quartzite | 2 | 7 | 7 | 3 | 7 | 2 | 6 | 4 | 6 | 6 | 8 | 7 | 6 | 4 |
| 2. Other rock grains | 5 | 5 | 9 | 3 | 8 | 3 | 8 | 6 | 7 | 3 | 7 | 4 | 3 | 3 |
| 3. Quartz | 80 | 68 | 71 | 83 | 67 | 79 | 67 | 67 | 63 | 63 | 64 | 52 | 42(?) | 44 |
| Feldspars | | | | | | | | | | | | | | |
| 4. Oligoclase and andesine | 6 | 5 | 2 | 4 | 4 | 9 | 5 | 11 | 8 | 15 | 5 | 16 | 14(?) | 16 |
| 5. Albite | P | P | 1 | P | P | P | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 |
| 6. Calcic plagioclase | — | — | R | — | R | R | P | P | P | P | P | P | P | P |
| 7. Microcline | 4 | 10 | 5 | 5 | 9 | 5 | 6 | 6 | 5 | 4 | 5 | 5 | 6 | 6 |
| 8. Orthoclase and sanidine | P | 1 | 1 | P | 1 | 1 | 2 | 2 | 3 | 2 | 2 | 2 | 3 | 2 |
| 9. Weathered feldspar | 2 | 2 | 2 | 2 | 3 | P | 4 | 2 | 4 | 4 | 5 | 3 | 4 | 2 |
| 10. Clay grains | — | — | — | — | R | — | R | R | P | R | 1 | 2 | 7 | 8 |
| 11. Muscovite | P | — | 2 | R | P | — | P | — | R | R | R | — | R | — |
| 12. Serpentine and/or chlorite | — | — | R | — | R | — | R | P | P | R | P | 1 | 1 | 1 |
| 13. Calcite | — | R | — | — | R | R | R | P | P | P | 1 | 5 | 7 | 8 |
| 14. Glauconite | — | — | — | — | — | — | R | R | P | P | P | P | P | P |
| 15. Volcanic glass | — | — | R | — | — | — | R | — | R | R | R | P | 2 | 1 |
| 16. Carbonaceous matter | R | R | R | — | — | — | — | R | — | — | P | P | 1 | P |
| HEAVY SEPARATES | | | | | | | | | | | | | | |
| % of heavy separate | | | | | 0.6 | 1.4 | 1.7 | 3.4 | 9.2 | 7.8 | 43.9 | 47.8 | 49.8 | 32.6 |
| Weight % of magnetics | | | | | 0.9 | 1.0 | 0.3 | 6.2 | 4.0 | 10.6 | 25.9 | 30.0 | 23.4 | 31.2 |
| Frequency % of other minerals on basis of 100% | | | | | | | | | | | | | | |
| 1. Ilmenite | | | | | 4 | 2 | 3 | 15 | 7 | 19 | 41 | 47 | 15 | 14 |
| 2. Leucoxene | | | | | R | P | 2 | P | 2 | 1 | 2 | P | 1 | P |
| 3. Limonite and hematite | | | | | 2 | P | 1 | 1 | 2 | 2 | P | P | 2 | 2 |
| 4. Pyrite | | | | | — | — | — | R | R | R | R | 2 | 3 | 49 |
| 5. Rock grains | | | | | 28 | 36 | 14 | 13 | 6 | 10 | 2 | 2 | P | P |
| 6. Epidote | | | | | 4 | 7 | 8 | 6 | 11 | 7 | 6 | 4 | 3 | 2 |
| 7. Zoisite | | | | | — | R | R | R | P | P | P | P | P | R |
| 8. Allanite | | | | | — | — | — | — | R | P | P | 1 | R | R |
| 9. Biotite | | | | | 3 | P | R | P | R | R | R | R | R | — |
| 10. Olivine | | | | | P | P | P | P | P | P | P | R | R | — |
| Pyroxenes | | | | | | | | | | | | | | |
| 11. Augite and diopside | | | | | 4 | 9 | 7 | 6 | 9 | 6 | 4 | 3 | 1 | 2 |
| 12. Diallage | | | | | 1 | 2 | 1 | 2 | 2 | 1 | P | P | P | P |
| 13. Brown pyroxene | | | | | 2 | 5 | 2 | 2 | P | 1 | P | P | R | R |
| 14. Hypersthene | | | | | P | 1 | P | 1 | 1 | P | P | P | P | R |
| Amphiboles | | | | | | | | | | | | | | |
| 15. Common bornblende | | | | | 3 | 6 | 8 | 6 | 11 | 8 | 3 | 3 | 3 | P |
| 16. Blue-green hornblende | | | | | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 1 | P | P |
| 17. Basaltic hornblende | | | | | — | — | P | — | R | R | P | P | P | P |
| 18. Actinolite and tremolite | | | | | 4 | 6 | 6 | 4 | 6 | 4 | 3 | 2 | 1 | P |
| Accessories | | | | | | | | | | | | | | |
| 19. Apatite | | | | | — | — | P | P | P | P | P | P | P | P |
| 20. Zircon | | | | | — | — | R | R | P | 1 | 6 | 7 | 10 | 10 |
| 21. Titanite | | | | | — | R | P | P | 2 | P | 2 | 2 | P | P |
| 22. Rutile | | | | | — | — | — | — | — | — | P | P | P | R |
| 23. Monazite | | | | | — | — | — | P | 2 | P | P | 1 | P | P |
| 24. Staurolite | | | | | P | 1 | P | P | P | P | P | — | R | R |
| 25. Andalusite | | | | | — | — | R | P | R | — | — | — | — | — |
| 26. Sillimanite | | | | | P | R | P | P | P | P | R | — | — | — |
| 27. Kyanite | | | | | P | P | P | P | P | P | R | — | — | — |
| 28. Chloritoid | | | | | — | — | — | — | — | R | — | — | R | — |
| 29. Tourmaline (a) | | | | | — | — | R | — | — | P | R | P | P | R |
| 30. Tourmaline (b) | | | | | — | — | R | R | R | P | R | P | P | R |
| 31. Tourmaline (c) | | | | | — | P | — | P | R | P | P | P | P | P |
| 32. Garnet (a) | | | | | P | 3 | 2 | 12 | 7 | 9 | 10 | 10 | 2 | P |
| 33. Garnet (b) | | | | | — | — | — | P | R | R | R | R | R | — |
| 34. Garnet (c) | | | | | — | R | R | 2 | P | P | 1 | P | P | R |
| 35. Dolomite and siderite | | | | | 33 | 14 | 36 | 19 | 24 | 22 | 12 | 8 | 49 | 15 |
| 36. Collophane | | | | | 6 | 1 | 2 | P | P | R | R | — | — | — |
| Ratio: Quartz to quartz plus total feldspar | 86 | 79 | 87 | 88 | 79 | 84 | 79 | 75 | 75 | 71 | 78 | 65 | 58 | 61 |
| Total pyroxenes | | | | | 8.3 | 16.9 | 10.8 | 11.9 | 13.2 | 9.2 | 5.2 | 4.3 | 2.1 | 1.9 |
| Total amphiboles | | | | | 10.7 | 15.1 | 18.2 | 14.3 | 21.4 | 16.0 | 8.1 | 6.7 | 4.8 | 1.3 |
| Total accessories | | | | | 0.0 | 0.0 | 1.1 | 0.8 | 4.2 | 1.8 | 9.5 | 10.8 | 11.4 | 12.3 |

P = Present in amounts less than one per cent but fairly common.
R = Rare.

seven samples studied, the determination of frequency percentages in 165 slides (not counting numerous duplicates run as checks) and the examination of many more.

### RESULTS OF THE ANALYSES

The mineral composition of the three pairs of samples is shown in Tables 1, 2, and 3. The composition of the various grades, and of the whole sample,[1] of the two samples of a pair are compared in parallel columns. Any material retained on the 14 mesh or coarser sieves was not analyzed, as the grains, unless crushed, are too large to be easily determined under the microscope. It was also found to be inadvisable, in most cases, to attempt to determine percentages of the various heavy minerals in grades coarser than the 65 mesh, because of the great number of composite grains and of the fact that the dark minerals appear opaque.

Frequency percentages in the tables are shown only to the nearest whole percent, since decimal figures give an impression of greater accuracy than is inherent in the method of analysis used (8). The figures for the total percentages of the pyroxenes, amphiboles, and the non-metallic accessory minerals of crystalline rocks were computed from the total number of grains counted in each of these groups, rather than from a summation of the percentages shown for the individual minerals. These data are given to tenths of a percent, but the decimal figure probably is not significant. The quartz to quartz plus total feldspar ratio is given to the nearest whole number, and was computed as follows:

$$\frac{\%\ \text{quartz}}{\%\ \text{quartz} + \text{total}\ \%\ \text{feldspar}} \times 100.$$

The total feldspar percentage was computed in the same manner as the other totals mentioned above, and includes weathered grains. Minerals which occur only in occasional samples are not shown in the tables. These will be listed and all of the minerals and mineral groups described in another article.

The size distribution of the more common minerals and mineral groups are also presented graphically (Figure 2). For the light minerals, only the quartz to quartz plus total feldspar ratio is given in the graphs. For the heavy minerals, distribution curves are shown for the magnetics, ilmenite, dolomite and siderite, pyrite, and total pyroxenes, amphiboles, accessories, and garnets.

*Size distribution of minerals within a single sample.* As shown by the tables and graphs, variation in the mineral composition of the different size grades of a single sample is very marked in every case. Although some of these variations are sporadic, certain well defined tendencies are evident:

(1) In general, the percentage of oligoclase and andesine, the most common feldspars in these samples,

[1] Material coarser than the 14 mesh seive (1.168 mm.) was removed before analysis of the whole sample. Samples M-968½ and M-972¼ were seived and bromoformed before it was discovered that a portion of the whole sample had not been split out, hence no data were secured on the whole samples of these two.

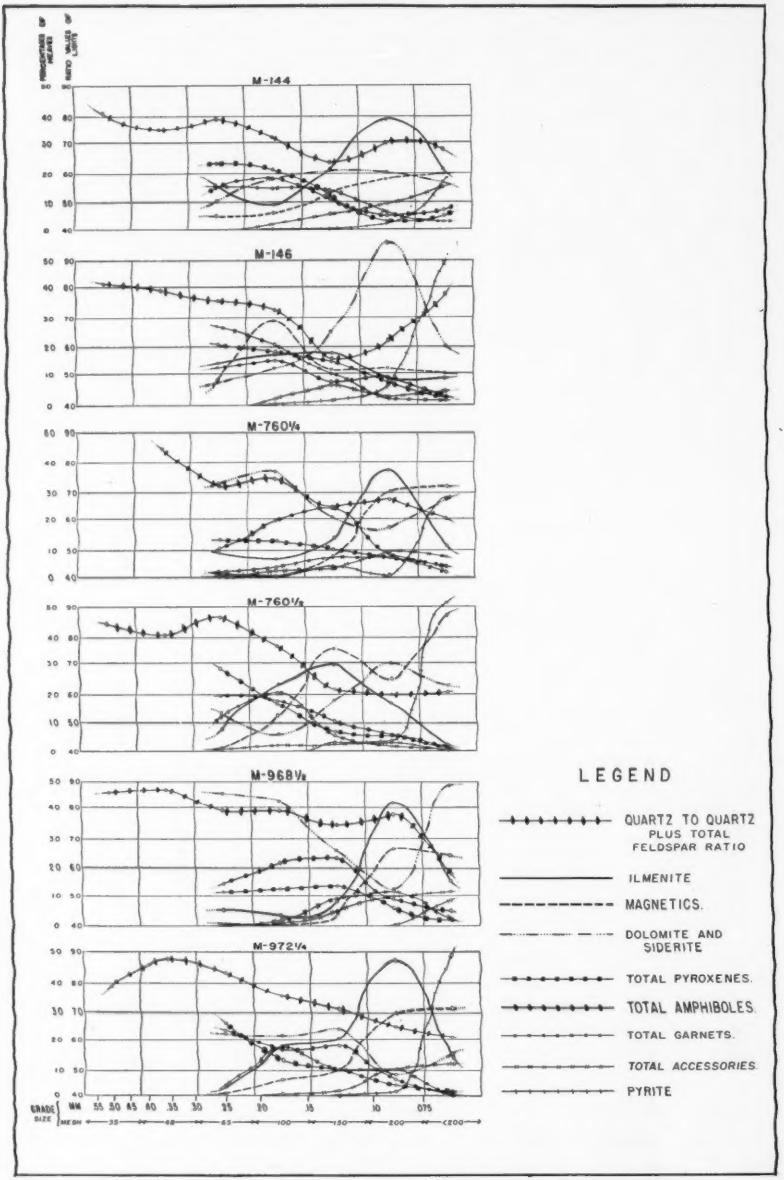


FIG. 2.—Size distribution curves of the common minerals and mineral groups in the samples described.

increases in the finer grades. Microcline, on the other hand, shows a slight tendency toward greater abundance in the coarser grades. The total feldspar content increases in the finer grades and the percentage of quartz decreases. This is best shown by the general, though irregular, decrease in the quartz to quartz plus total feldspar ratio.

(2) Calcite is much more abundant in the finest size, passing the 200 mesh sieve, than in any other grade. The 200 mesh grade also contains considerable amounts of this mineral.

(3) Serpentine and chlorite (grouped together), glauconite, volcanic glass, carbonaceous matter (coal), and composite grains of the clay minerals, though not abundant in any grades, are more common in the finer ones.

(4) The pyroxenes and amphiboles show an increase to a maximum in the 100 or 150 mesh grade, followed by a decrease. The lower percentages of these minerals in the 65 mesh grade is principally due to the large amounts of rock (composite) grains in this size grade. Were these disregarded, all the minerals would show higher percentages in this grade and the pyroxenes and amphiboles would show a more uniform decrease in percentage from coarse to fine.

(5) The distribution of the garnets is similar to that of the pyroxenes and amphiboles.

(6) The accessories show an increase in percentage in the finer grades, reaching a maximum either in the 200 mesh grade or in the finest material, passing the 200 mesh seive.

(7) Pyrite shows a very marked concentration in the finest material.

(8) The metallic minerals, since they are the highest in specific gravity, show the effects of sorting most markedly. They usually rise to a pronounced maximum in one of the three finest grades, then decrease in percentage. This is shown very well by the graphs of Figure 2, where pronounced modes are evident on most of the curves for the magnetics and for ilmenite.

(9) The distribution of dolomite and siderite is quite erratic. This may be due to the fact that the dolomite, much the more common of these two minerals, has a specific gravity very close to that of the bromoform used to concentrate the heavy minerals from the rest of the sample. Slight variations in the specific gravity of the bromoform, or in the time taken to make the separation, would therefore affect the percentages of this mineral in the heavy separates.

(10) Rock grains (composite grains) are, of course, more abundant in the coarser size grades.

Certain of the less common minerals also show the effects of size distribution. Collophane is more abundant in the coarser grades. Sillimanite and kyanite also appear to be more abundant in the coarser portions of the samples.

These results are in agreement with those of other workers except Trowbridge and Shepard. Their results show plagioclase more abundant in the coarser grades and hornblende more common in the finer portions of the samples. Probably this is due to original differences in the sizes of

these minerals in the source rocks of the sediments which they studied.

*Comparison of the pairs of samples.* The composition of the whole samples of M-144 and M-146 and of M-760¼ and M-760½, show some decided differences between the two samples of the pairs. Both pairs show marked differences in the percentages of quartz and of oligoclase and andesine, and in the quartz to quartz plus total feldspar ratio. There are also notable differences in the percentages of ilmenite, rock grains, and accessories of M-144—M-146, and in the magnetics, pyrite, rock grains, dolomite and siderite, pyroxenes, and amphiboles of M-760¼—M-760½. There are also differences in percentages of some of the less common minerals.

Though these differences may not appear to be very great, they actually are of sufficient magnitude to seriously impair the accurate comparison of the samples. Progressive downstream changes in the composition of samples from the Mississippi River are not great, and variations such as shown by the analyses would, to a considerable extent, obscure the progressive changes.

In most cases, decided differences are also evident between the same grades of the two samples of a pair, particularly in the percentages of the heavy minerals, which show even greater differences than the analyses of the whole samples. These differences may be easily seen in the graphs by taking the point on each curve where intersected by a vertical line representing any given size, and comparing with the equivalent points on the same curves of the other samples. In some cases one, or even two, grades show nearly the same composition in one pair of samples, but the same grade or grades differ widely in composition in another pair. No single grade or group of grades can be chosen which will reconcile the differences in composition between the two samples of each of the three pairs. The 200 mesh grade comes nearest to yielding comparable results for all of the pairs.

The causes of these variations in percentages of the minerals in different size grades of the same sample, and of differences between samples differing in average grain size and sorting, have been adequately discussed by Rubey (3), as far as the heavy minerals are concerned. He concludes that they are due to sorting, differential abrasion, and initial differences in the sizes of the various minerals. Rubey, however, only considers the effects of sorting on the basis of specific gravity; sorting on the basis of shape may also be important.

The same factors which determine the distribution of the heavy minerals must also govern the distribution of the lights. However, since quartz and the feldspars, the dominant light minerals, have nearly the same specific gravity, the differences in distribution of these minerals must be due chiefly to initial differences in size. Sorting on the basis of shape may also be an important factor in some cases, but does not appear to be so in the samples studied. Neither

does differential abrasion appear to be of much importance.

Since analyses of the whole samples, or of single grades or groups of grades from each sample, could not be used for purposes of comparison, the data of the analyses were used to test various comparison methods, in the hope that a satisfactory one could be discovered. Of the various methods tried, the one which gave the best results for the heavy minerals was that suggested by Rubey. This consists of averaging the percentages of the various heavy minerals from two grades of each sample, one of the grades being the same *actual* size for each sample, to eliminate variations due to initial differences in sizes of the minerals, the other being the same *relative* size with respect to the sorting of the sample, to eliminate variations due to differences in sorting. This method allows for a number of possibilities in the choice of these two grades. Any one of the five grades analyzed for heavy mineral content could be used for the grade of the same actual size for each sample. For the same relative size, any grade occupying a definite position with respect to the size frequency distribution of the sample could be chosen. Some of these possibilities were eliminated by inspection of the data in the tables and graphs. The others were tested by averaging the composition of the two grades chosen and comparing the results. Though other methods gave better results in single cases, the best results for all three pairs of samples were secured by using the 200 mesh grade, for the grade of the same actual size for all samples, and a grade midway between the grade containing the maximum amount of material and the finest material, for the same relative size. In the case of a poorly sorted sample, such as M-144, where no marked concentration of material in any particular size grade occurs, this relative size was picked as midway between the grade containing the mean grain size and the finest material. In the samples studied, this midway grade is as follows: Sample M-144, the 65 mesh; sample M-146, the 150 mesh; sample M-760¼, the 200 mesh; sample M-760½, the 150 mesh; sample M-968½, the 200 mesh; sample M-972¼, the 150 mesh. For purposes of comparison of the heavy minerals, then, the composition of each of the grades listed above must be averaged with the composition of the 200 mesh grade of that particular sample. In samples M-760¼ and M-968½, only the 200 mesh grade must be analyzed, since in these samples this grade is the "midway grade" as well as the one chosen for analysis in all of the samples.

In the case of the light minerals, which differ only slightly in specific gravity and shape, and whose variations in distribution are therefore chiefly due to initial differences in size rather than to sorting, the analysis of a single size grade, the 100 mesh, was found to give a satisfactory basis for comparison.

The results of this method of comparison are shown in Table 4. It will be noted that most, but not all, of

TABLE 4. *Comparison of the pairs of samples*

| Mile no. | 144 | 146 | 760¼ | 760½ | 968½ | 972¼ |
|---|---|---|---|---|---|---|
| *LIGHT SEPARATES* (frequency % of minerals in 100 mesh grade). | | | | | | |
| 1. Chert and fine-grained quartzite | 7 | 13 | 6 | 6 | 6 | 4 |
| 2. Other rock grains | 9 | 6 | 10 | 10 | 8 | 6 |
| 3. Quartz | 60 | 58 | 61 | 65 | 67 | 67 |
| Feldspars 4. *Oligoclase and andesine* | 9 | 10 | 7 | 7 | 5 | 11 |
| 5. Albite | P | 1 | P | P | 1 | 1 |
| 6. Calcic plagioclase | P | P | P | P | P | P |
| 7. *Microcline* | 8 | 5 | 5 | 4 | 6 | 6 |
| 8. Orthoclase and sanidine | 3 | 3 | 2 | 2 | 2 | 2 |
| 9. Weathered feldspar | 4 | 4 | 7 | 6 | 4 | 2 |
| 10. Clay grains | R | R | P | P | R | R |
| 11. Muscovite | R | R | P | R | P | — |
| 12. Serpentine and/or chlorite | P | P | P | R | R | P |
| 13. Calcite | R | R | P | R | R | P |
| 14. Glauconite | — | R | R | R | R | R |
| 15. *Volcanic glass* | R | P | R | — | R | — |
| 16. Carbonaceous matter | R | R | P | — | — | R |
| *HEAVY SEPARATES* | | | | | | |
| Grades averaged | 65 & 200 | 150 & 200 | 200 | 150 & 200 | 200 | 150 & 200 |
| Weight % of magnetics | 11.7 | 12.0 | 30.3 | 30.7 | 25.9 | 20.3 |
| Frequency % of other minerals on basis of 100% | | | | | | |
| 1. Ilmenite | 24 | 13 | 36 | 22 | 41 | 33 |
| 2. Leucoxene | 2 | 3 | 4 | 7 | 2 | 1 |
| 3. Limonite and hematite | 3 | 4 | 4 | 14 | P | 1 |
| 4. Pyrite | 1 | 4 | 1 | 4 | R | 1 |
| 5. Rock grains | 18 | 2 | 1 | 3 | 2 | 6 |
| 6. Epidote | 7 | 4 | 5 | 4 | 6 | 6 |
| 7. Zoisite | R | R | R | R | P | P |
| 8. Allanite | X | X | — | — | P | P |
| 9. Biotite | R | R | P | P | R | R |
| 10. Olivine | R | R | — | R | P | R |
| Pyroxenes 11. Diopside and augite | 5 | 8 | 5 | 4 | 4 | 5 |
| 12. Diallage | 1 | 1 | 1 | P | P | P |
| 13. Brown pyroxene | 2 | P | P | 2 | P | P |
| 14. Hypersthene | 1 | 1 | P | P | P | P |
| Amphiboles 15. Common hornblende | 4 | 5 | 5 | 4 | 3 | 6 |
| 16. Blue-green hornblende | 1 | 1 | 1 | 2 | 2 | 3 |
| 17. Basaltic hornblende | P | P | P | P | P | R |
| 18. Actinolite and tremolite | 2 | 1 | 2 | 2 | 3 | 3 |
| Accessories 19. Apatite | P | 1 | 1 | P | P | P |
| 20. Zircon | 4 | 2 | 5 | 2 | 6 | 4 |
| 21. Titanite | P | P | 2 | P | 2 | 1 |
| 22. Rutile | X | R | 1 | P | P | R |
| 23. Monazite | — | P | R | R | P | P |
| 24. Staurolite | R | R | P | R | P | R |
| 25. Andalusite | — | X | — | X | — | — |
| 26. Sillimanite | P | R | P | R | R | R |
| 27. Kyanite | R | R | R | R | R | R |
| 28. Chloritoid | X | — | — | X | — | X |
| 29. Tourmaline (a) | R | R | P | P | R | P |
| 30. Tourmaline (b) | R | R | P | P | R | P |
| 31. Tourmaline (c) | X | X | P | P | P | P |
| 32. Garnet (a) | 7 | 5 | 6 | 3 | 10 | 9 |
| 33. Garnet (b) | P | R | P | P | R | R |
| 34. Garnet (c) | P | P | 1 | P | 1 | P |
| 35. Dolomite and siderite | 14 | 39 | 17 | 23 | 12 | 15 |
| 36. Collophane | R | P | P | R | R | — |
| Ratio: Quartz to quartz plus total feldspar | 71 | 72 | 74 | 77 | 79 | 75 |
| Total Pyroxenes | 9.6 | 10.8 | 6.9 | 6.4 | 5.2 | 6.8 |
| Total Amphiboles | 7.6 | 7.7 | 8.1 | 8.0 | 8.1 | 11.4 |
| Total Accessories | 4.8 | 4.4 | 9.3 | 3.0 | 9.5 | 6.3 |

P = Present in amounts less than one percent but fairly common.
R = Rare. X = Rare in one of the two grades averaged; absent in the other.

the differences in composition between the two samples of a pair, are eliminated. In the case of minerals such as magnetite and ilmenite, which are particularly susceptible to the effects of sorting, due to their very high specific gravities, the method fails to eliminate all of the differences. Also, due to the sporadic distribution of the dolomite and siderite, not all of the differences in percentages of these minerals are eliminated. Finally, the differences between a very poorly sorted sample, such as M-144, and a well sorted one, such as M-146, are not completely removed. The results, however, are greatly superior to those achieved by the use of other methods.

## CONCLUSIONS

In most studies of detrital sediments, the heavy minerals are separated, and their percentages determined, either from the sample as a whole, or from a single size grade or group of size grades. Percentage determinations of the light minerals are usually made on the whole sample, if made at all. These methods preclude the accurate comparison of samples differing in average grain size, or in sorting, or in both of these features.

In the case of the light minerals, this difficulty can be largely obviated by analyzing a single size grade from each sample, providing the grade chosen represents the average composition of the light portion, and is near the central part, of the average sample. In the Mississippi River samples studied, the 100 mesh grade fulfilled these requirements and gave the best results.

Satisfactory results for the heavy minerals can be secured only by averaging the percentages of the heavy minerals in two size grades of each sample. One of these grades should be the same for all samples, the other should occupy a definite position with respect to the size frequency distribution of the sample. The 200 mesh grade, and a grade midway between the grade containing the maximum amount of material and the finest material, were the two grades which gave the best basis for comparison in the samples studied.

In sediments of somewhat different character from those studied by the writer, a choice of different size grades may be advisable. However, in view of their variation in grain size and sorting, and the variety of minerals present, Mississippi River sands should yield results applicable to sandy sediments in general.

The writer is well aware of the fact that there are many types of sediment studies where the time involved in determining the heavy mineral composition of two grades from each sample is not justified. Even in studies where a comparison is made of the percentages of individual minerals in a series of samples, this procedure is not necessary if the samples are fairly uniform in degree of sorting and in grain size. But if the samples differ in average grain size or sorting, which they frequently do, the use of this method, or a similar one, is es-

sential to accuracy in any study involving the detailed comparison of mineral percentages in a series of samples.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 6, NO. 3, PP. 143–153, FIGS. 1–3, TABLES I–V, DECEMBER, 1936

# PETROGRAPHY AND DISTRIBUTION OF A HIGHLY WEATHERED DRIFT IN THE KANSAS RIVER VALLEY

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ABSTRACT

In the valley of the Kansas River as well as on the adjacent uplands between Manhattan and Kansas City, Kansas, is a red clay-like deposit of very fine texture and low textural range. Field studies and laboratory investigations consisting of mechanical and mineralogical analyses tend to prove that the upland phase is a very highly weathered till, whereas the terrace deposit is fluviatile in origin, the materials of which have been derived from the upland deposits. No definite age has been assigned to these clays.

In the fall of 1931 the attention of the writer was called to a red clay-like material in the valley of the Kansas River in the vicinity of Lawrence, Kansas, by Dr. W. H. Schoewe, Associate Professor of Geology in the University of Kansas. Since the character of these deposits had not previously been studied in detail, and since the origin was unknown, the writer at the suggestion of Dr. Schoewe undertook the necessary field work of which the results are incorporated in this paper.

The study of the red clay-like deposits resolved itself into (1) Detailed mapping of the deposits, (2) Laboratory study of the lithologic character of the deposits, (3) Classification of the deposits based on physiographic distribution and lithologic character, and (4) Origin of the deposits.

*Acknowledgments.*—The writer wishes to express his appreciation to the Kansas Geological Survey for the loan of special field equipment. Especial indebtedness is due to Dr. Walter H. Schoewe for suggesting the problem and for his help both in the field and office and for advice and criticism in preparing this manuscript.

*Location.*—The area investigated in the study of the red clay-like deposits is in eastern Kansas and extends eastward along the Kansas River from Manhattan, Riley County, to Kansas City, Kansas, a distance of one hundred and fifty miles. The original plan was to consider only the actual valley of the Kansas River, between bluff and bluff, but it became apparent as the field work progressed that it was necessary to examine a much larger territory in order to comprehend more fully the problem of the red clay-like deposits, hence all the larger tributaries of the Kansas River as well as a narrow strip of the upland immediately adjacent to the river were included in the area of investigation. The width of the area studied varies from three to ten miles.

## OCCURRENCE OF THE DEPOSITS

*General Relations.*—Physiographically the area of the red-clay-like deposits lies in the extreme southern

portion of the Dissected Till Plains Section of the Central Lowlands Province as defined by Fenneman (1). Recently Schoewe (2) has extended the area of the glacial drift in Eastern Kansas between fifteen and twenty miles south of the Kansas River, hence the area of the red clay-like deposits lies well within the southern boundary of the Dissected Till Plains Province and not on the margin.

The Kansas River, an old age stream, flows through the area in a broad flood plain consisting largely of fine gray sand. This flood plain is practically without relief except for long linear depressions bounded by low ridges or natural levees. The width of the valley varies from place to place due to the character of the bed-rock of the area which consists of an alternating series of limestones and shales that belong to the Virgil and Missourian series of the Pennsylvanian (3) and to the Big Blue group of the Permian. Where the valley is wide the bed-rock contains a minimum of limestone and a maximum of shale; where narrow there is a maximum of limestone and a minimum of shale.

The bluffs on either side of the river also reflect the lithology of the bed-rock series. At Manhattan, Riley County, and at Kansas City, where the bed-rock consists largely of limestone, the bluffs are very steep and precipitous. From Wabaunsee, Wabaunsee County to Topeka, Shawanee County, the bed-rock of the region contains a minimum of limestone and a maximum of shale with the result that the bluffs along the river are lower and less steep due to the differential weathering of limestone and shale.

FIG. 1.—Terrace of red clay-like material in northern portion of Wabaunsee County, Kansas.

In this area the red clay-like deposits occur typically in three topographic positions namely: (1) on terraces in the Kansas River valley, (2) on the upland and on upland spurs, and (3) in the swales or the undissected areas at the heads of tributary valleys.

*Terraces.*—The terraces are located near the junction of tributary streams with the Kansas River and vary in area from 4 to 5 square miles, as in Wabaunsee County, to 1/16 of a square mile as in Jefferson County. The thickness of the material ranges from 12 to 30 feet.

In the entire northern portion of Wabaunsee County, the red material forms a broad terrace facing the Kansas River that is 12 to 20 feet high. Excellent exposures are shown in the road cuts where north-south roads cross the face of the terrace as in a cut along Kansas State Highway No. 11 approximately ¼ mile north of Highway No. 29. Here the red material is 20 feet thick (fig. 1).

In an exposure in a terrace in the northern portion of Johnson County the red clay-like material is overlain by 3 feet of river silt.

Two terraces of the red clay-like material, an upper and a lower one occur on the north side of the Kansas River along Matoon Road in the southwest portion of Kansas City, Kansas. The lower terrace which rises 40 feet above the flood plain of the Kansas River is a rock bench capped by red clay-like material. The

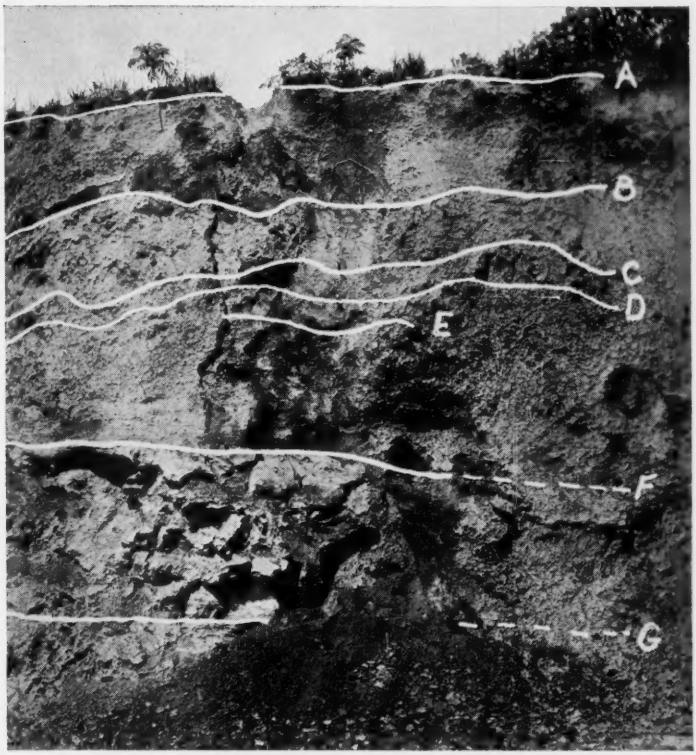


FIG. 2. Exposure on W. side of Matoon Road. A–B Red clay-like deposit. B–C. Red and gray mottled material. C–D Pebble band. D–E Sand on irregular surface below, in some places includes a pebble band. E–F Weathered, gray clayey material containing weathered glacial boulders. F–G Bed-rock forming bench on which material above has been deposited.

section shown in this exposure (illustrated in fig. 2) is as follows:

| | Ft. | In. |
|---|---|---|
| Red clay-like material | 3 | 0 |
| Red and gray mottled clayey material | 2 | 6 |
| Pebble band and sandy material | 0 | 8 to 1 4 |
| Gray, clayey, highly weathered material containing weathered boulders suggestive of old glacial drift | 3 | 10 |
| Dense, massively bedded limestone | 3 | 8 |

On the south side of the Kansas River along the west side of the S.W. ¼ Sec. 33, T. 11 S., R. 24 E., Wyandotte County, along the Argentine-Holliday road, three occurrences of the red clay-like material are to be seen namely on the upland, on an upper terrace, and on a lower terrace. The vertical section exposed along the road is as follows:

| | Ft. | In. |
|---|---|---|
| Red clay-like material covering upland | 2 | 6 to 4 0 |
| Red clay-like material covering rock bench (upper terrace) | 1 | 8 |
| Red clay-like material forming broad lower terrace | 15 | 0 |
| Red clay-like material forming terrace with yellowish silt-like covering near the Kansas River | 15 | 0 |
| Yellow silt-like material between lower terrace and river | 15 | 0 |

The upper terrace, 20 feet below the upland level, is traceable around the upland spurs into the swales at the heads of the valleys tributary to the Kansas River. Of the two terraces in the Kansas City region, the lower one is correlated with the terrace found in the western portion of the area. This correlation is based on a study of the elevations of the upland, terrace, and the river bed at Kansas City, Buck Creek, and Wabaunsee. As may be seen in table I, the lower terrace at Kansas City, when projected up stream ties in with the Wabaunsee and Buck Creek terraces better than does the upper terrace of the Kansas City area.

*Upland.*—The red clay-like materials have a patchy distribution on the upland. The exposed thickness varies from 2 to 17 feet. Many excellent exposures of this upland phase showing thicknesses from 10 to 17 feet have been made in Douglas and Johnson Counties in recent regrading of state highway number 10. In eastern Douglas county, in the N.E. corner Sec. 8 and 10, T. 13 S., R. 21 E., the red clay-like deposit rests directly on glacial till. In these exposures are small siliceous pebbles which are relatively larger and more numerous at the base than at the top and in some instances pebbles are entirely absent in the upper few inches of the deposit. The gradation of the red clay-like material into

TABLE I. *Table showing elevations of upland and two terraces with elevations of the Kansas River for comparison (elevations computed from mean tide level).*

| Physiographic Feature | Kansas City | Buck Creek Jefferson Co. | Wabaunsee County |
|---|---|---|---|
| Upland | 1000–1100′ | 1000–1150′ | 1200–1300′ |
| Upper Terrace | 900– 950′ | | |
| Lower Terrace | 800– 850′ | 850– 900′ | 1025–1050′ |
| Kansas River | 725– 750′ | 800– 825′ | 950– 975′ |

glacial drift is definitely shown in the Eastern Douglas County outcrops.

Where the red clay-like material is found occupying the spurs and noses of the upland, it seldom shows a thickness of over 2 to 3 feet. However due to the absence of exposures having a greater depth the true thickness of this phase of the deposit could not be acertained.

*Swales.*—The undissected bowl-shaped portions of the tributary valleys to the Kansas River are here designated swales. These are drained by sheet wash instead of streams. The red material in the swales corresponds to that capping the upland.

## CHARACTER AND DESCRIPTION OF THE RED CLAY-LIKE DEPOSITS

*Characteristic Features.*—The red clay-like materials display a number of constant characteristics that serve to make recognition easy. They have a decidedly red color and outcrops stand in steep banks with little or no slumping. They exhibit a decided tendency to break as a joint clay though when wet they become very sticky and plastic. Locally they are somewhat sandy. Where the oxidized outer few inches of the material have been removed, as may be seen in recently made road cuts, a zoned appearance is commonly noticible. In such exposures the upper 2 or 3 feet form a red zone that shades downward into a red and gray mottled basal portion.

*Texture, Structure, and Thickness.*—The deposits consist of a fine-grained homogeneous material that shows no indication of bedding. As may be seen from table II, the thickness of the red material varies with the physiographic position, reaching its maximum development in the terraces.

TABLE II. *Relation of physiographic location to thickness*

| Physiographic Location | Minimum Thickness | Maximum Thickness | Avg. |
|---|---|---|---|
| Terrace..... | 15′ | 35′ | 25′ |
| Upland..... | 2′ | 17′ | 9′6″ |
| Swale..... | 3′ | 10′ | 6′6″ |
| Nose or Spur... | 3′ | 5′ | 4′ |

The great variation in the thickness of the upland deposits may be due either to variations in original deposition, or to removal after deposition.

The fine clayey matrix contains siliceous materials that vary in size from small grains 1 mm in diameter to pebbles measuring from 5 to 6 centimeters in the longest dimension. The smaller pebbles are mostly distributed near the top of the deposit but near the base they become larger and more numerous. The pebbles are mainly composed of chert or chalcedony. Those that occur in the upper portion of the deposit have a more or less weathered appearance. Where the deposit occurs on the uplands, the pebbly phase grades downward into an unquestionable till. Excellent outcrops showing the transition from fine to coarse pebbles in the clayey matrix occur in the newly made road cuts along Kansas State Highway 10 east and west of Eudora in Douglas County.

The deposits when tested with a 10% solution of hydrochloric acid in the field showed no reaction for calcium carbonate but composite samples treated in the laboratory with a 50% solution of the acid gave a feeble calcium carbonate test.

In order to study in greater detail the character of the deposits, samples were collected from typical outcrops as shown in table III and subjected to laboratory study.

*Mechanical Anslysis.*—The materials were sieved and histograms were constructed. A study of the histograms shows that in each case the material is fine grained and has a low textural range. It is at once apparent (fig. 3) that the histograms may be classified into two groups, one in which there are two maxima, and a second group in which there is but a single maximum. The former indicates a poorer degree of sorting than the latter, hence two modes of origin of the red clay-like material are suggested. As shown by histograms 1–3 and 7–12 (fig. 3) the red clay-like materials coating the upland proper, the upland noses or spurs, and present in swales all give the same type of histogram in that each shows two maxima indicating a low degree of sorting whereas histograms 4–6 (fig. 3) were constructed from the result of analyses of terrace deposits and show a single maximum thus indicating a higher degree of sorting. Two exceptions to the generalization, that the materials occurring in a terrace position are highly sorted and those on the upland are not, are shown in histogram 12, the material for which was collected from a terrace-like rock bench, better classified as an intermediate upland, and second in histogram 2 the material for which was collected from an upland spur or nose and which shows a high degree of sorting. The first exception may be explained on the basis of similarity to the swale type of occurrence, and the second on the basis that the location from which that particular sample was collected was in a position especially favorable to the reworking of the red clay-like deposits of the upland phase by sheet wash.

Histograms 1–3 and 7–12 (fig. 3) should be compared with histogram 13 which shows the texture and sorting of a probable residual limestone soil of the upland.

*Mineralogical anslysis.*—The first step in the mineralogical analysis was to remove the coating of red coloring matter surrounding the individual grains. This was accomplished by placing the sample in a beaker and boiling in a 50 per cent solution of HCl. After the boiling process had been completed, the color free screenings were washed, thoroughly dried, and studied. The results of this study are tabulated in table IV.

It is interesting to note that with the exception of the clay and three occurrences of particles of feldspar, all the constituents of the red clay-like material are siliceous. This fact indicates that the material is very highly leached.

The approximate relative amounts of the various mineralogical constitu-

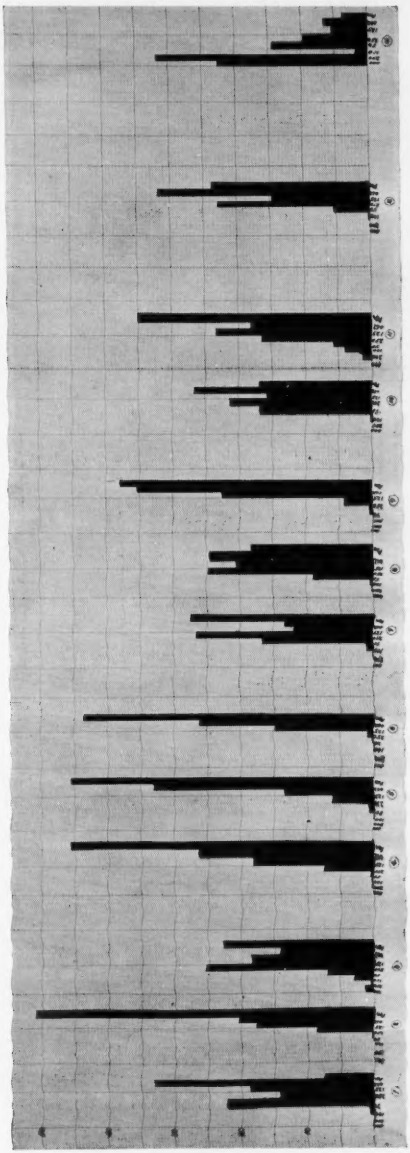

FIG. 3.—Histograms showing results of mechanical analyses.

TABLE III. *Locations of samples analyzed.*

| Histogram No. | Physiographic position | Location |
|---|---|---|
| 1 | Spur or Nose | N.W. Cor. Sec. 21, T. 11 S. R. 13 E. |
| 2 | Spur or Nose | S.W. Cor. Sec. 16, T. 12 S. R. 24 E. |
| 3 | Spur or Nose | Center S. side S.W. ¼, S.E. ¼, Sec. 11, T. 11 S., R. 16 E. |
| 4 | Terrace | Center E. side S.W. ¼, Sec. 21, T. 10 S., R. 10 E. |
| 5 | Terrace | Center E. side S.W. ¼, Sec. 7, T. 11 S., R. 25 E. |
| 6 | Terrace | N.W. corner S.W. ¼, Sec. 27, T. 11 S., R. 19 E. |
| 7 | Upland | S.W. edge of Eudora, Douglas County |
| 8 | Upland | N.E. corner Sec. 1, T. 13 S., R. 21 E. |
| 9 | Upland | Center E. side Sec. 27, T. 12 S., R. 22 E. |
| 10 | Swale | Center E. side Sec. 36, T. 10 S., R. 13 E. |
| 11 | Swale | Section 28, T. 12 S., R. 22 E. |
| 12 | Upper Terrace | W. side S.W. ¼, Sec. 33, T. 11 S., R. 24 E. |
| 13 | Upland (Residual) | Center E. side Sec. 33, T. 13 S., R. 19 E. |

TABLE IV. *Table showing results of mineralogical analyses*

| No. of histogram | Clay Particles cles | Quartz Grains | Chert Flakes | Sandstone Pebbles | Quartzite Pebbles | Chalcedony | Feldspar |
|---|---|---|---|---|---|---|---|
| No. 1 | X | X | X | X | | | X |
| No. 2 | X | X | X | | | | |
| No. 3 | X | X | X | X | | | X |
| No. 4 | X | X | X | | | | X |
| No. 5 | X | X | X | | | X | |
| No. 6 | X | X | X | | | X | |
| No. 7 | X | X | X | | X | X | |
| No. 8 | X | X | X | | | | |
| No. 9 | X | X | X | | | X | |
| No. 10 | X | X | | | | | |
| No. 11 | X | X | X | X | | X | |
| No. 12 | X | X | X | | | | |

ents of the samples analyzed are shown in table V.

TABLE V. *Table showing approximate percentages of various mineral constituents of the red clay-like deposits.*

| Constituents | Relative percentage |
|---|---|
| Quartz Grains—angular to rounded | 10–20 |
| Chert | 5–15 |
| Chalcedony-rounded and polished | 1– 2 |
| Quartzite | less than .25 |
| Sandstone | less than .25 |
| Feldspar | .5 |
| Clay Particles | 62–83 |

*Color.*—The red deposit owes its color to an iron oxide film that coats the individual particles. This may have developed from the weathering of original iron bearing minerals.

### ORIGIN OF THE DEPOSIT

There are five possible explanations for the origin of the red clay-like deposits. The material may be (1) residual soil, (2) weathered loess, (3) a lacustrine deposit, (4) a fluviatile deposit, and (5) the upper portion of a highly weathered glacial drift. From the physiographic positions of the red clay-like deposits and from a comparative study of the histograms shown in fig. 3, it is apparant that

two phases of materials are present, an upland-swale phase, and a valley phase, and that two modes of origin are represented.

*Origin of the Upland Phase.*—On the basis of similarity of character, as shown in the field studies and by histograms 1, 2, 3, 7, 8, 9, and 11 (fig. 3), the red clay-like deposits found on the upland and in the swales may be considered as having a common origin.

Of the five possible origins suggested, the drift hypothesis of origin is the most tenable for the origin of the upland phase. The evidence favoring the drift hypothesis is as follows:

(1) The presence of the red clay-like material on the upland and in the swales may be explained as representing a very highly weathered portion of a glacial drift. Mechanical analyses of these deposits show that the material is poorly sorted, a characteristic typical of till.

(2) In the northeastern portion of Douglas County, in the vicinity of Eudora, the red material directly overlies an unmistakable till. Here the red clay-like material contains pebbles which become larger and more numerous toward the basal portion of the deposit, grading finally into a true till.

(3) The red clay-like material is very sticky when wet similating the gumbotil of Iowa which according to Kay (4), is a very highly weathered till.

(4) The drift origin of these deposits is suggested by the absence of stratification, the wide spread distribution, and varying thickness of the material.

The complete lack of sorting as seen both in the field and from the histograms and the presence of numerous pebbles does not support a possible eolian hypothesis of origin. A lacustrine or fluviatile origin is unlikely since there is a complete lack of physiographic evidence of lakes or streams at the upland level. The residual soil origin for this deposit is improbable because in no place in the area studied did the deposit grade downward into the bedrock of the region and in each instance where the base was exposed the red clay-like material graded downward into an unmistakable till.

*Origin of the valley deposits.*—The red clay-like deposits found in the valley of the Kansas River are associated with terraces. In general these deposits are similar to those occurring on the upland, but differ in that the terrace deposits are well sorted whereas the upland material is not. Compare histograms 4, 5, and 6 with 1, 2, 3, 7, 8, 9, and 11.

As in the case of the upland phase, there are five possible origins to explain the origin of the valley phase of which the fluviatile hypothesis is the most acceptable. The evidence favoring the fluviatile hypothesis is as follows:

(1) The well sorted nature of the material and the physiographic expression of the deposits as terraces along the Kansas River.

(2) A study of the surface levels of the terraces between Manhattan and Kansas City, Kansas, shows a

profile that is parallel to that of the Kansas River.

(3) Histograms of the terrace deposits show that the material is well sorted.

(4) Transportation of materials over great distances by streams of low gradients would give rise to well sorted deposits such as the red clays of the terraces.

(5) The presence of rounded pebbles as well as the general low textural range of the material are favorable to this hypothesis.

It is true that some of the nose and swale deposits are well sorted (see histograms 2 and 11, fig. 3). This sorting suggests aqueous origin but may be accounted for on the basis of reworking the highly weathered drift deposits by sheet wash.

On the other hand the gradation of the pebbles in regard to size and number from top to bottom is not so readily accounted for on the basis of the fluviatile hypothesis. It would have to be assumed that the velocity of the stream fluctuated from time to time and that during the later stages in the deposition of the material fewer and smaller pebbles were available for transportation. The absence of stratification in the terrace deposits argues against an aqueous origin but the lack of bedding may possibly be attributed to a long period of weathering during which all stratification has been obliterated. In the upper terrace at Kansas City, the red clays grade downward into sandy to gravelly material containing considerable clay. This phase is either highly weathered gravel in which various igneous rocks have decomposed to form the clayey material or else the lower portion of the deposit is a till. Since the Kansas City upper terrace is the only one in which coarser material lies at the base, the writer hestitates to consider the lower portion just described as representing a true till.

The constant presence of pebbles from 1 to 5 mm in diameter, a size too large to have been moved to their present position by the wind and too numerous to be explained on the basis of burrowing animals does not support an eolian hypothesis of origin. A lacustrine hypothesis lacks evidence due to the conformity between the slope of the terrace levels and the slope of the profile of the Kansas River and the total lack of any field evidence of post-Tertiary diastrophism. The mechanical analyses of the valley deposits as well as the lack of field evidence also do not support either a drift or a residual hypothesis of origin.

The evidence therefore is more favorable to the fluviatile hypothesis of origin than any other for the origin of the valley phase of the red clay-like deposits.

### AGE OF THE DEPOSITS

The age of the red clay-like deposits is not definitely known except that they are younger than the tills from which they are considered to have been formed. Schoewe has tentively assigned all the drift in northeastern Kansas to the Kansan stage of glaciation. Leverett, on the other-hand, has referred an old patchy drift

in Missouri, similar to that described by Schoewe and occupying the same relative geographic position in regard to the previously mapped glacial border, to the Nebraskan stage of glaciation. The upland red clay-like deposits are hence considered post Nebraskan or post Kansan in age, probably the latter. The terrace materials are believed to have been derived from the upland deposits and thus are of later origin. No data are available to date the age of these deposits more accurately.

SUMMARY

In summary the upland phase of the red clay-like deposits appears to be an extremely highly weathered till and the terrace phase of the deposits is probably of fluviatile origin the composing material having been derived from the upland deposits.

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JOURNAL OF SEDIMENTARY PETROLOGY, VOL. 6, NO. 3, PP. 154–157,
DECEMBER, 1936

# DETERMINATION AND CALCULATION OF SPHERICITY VALUES OF PEBBLES

F. J. PETTIJOHN

ABSTRACT

An alinement chart for simplifying computations of sphericity based on Wadell's "practical" formula for pebbles and small cobbles is presented with an explanation of its use.

A clastic sediment is an aggregate of grains or fragments of pre-existing materials. These component units have four fundamental properties, namely, (1) size, (2) mineral composition, (3) shape, and (4) surface texture (frosting, striations, etc.) The first two have been rather fully studied by sedimentologists but only more recently has the shape of sedimentary materials received much attention (1).

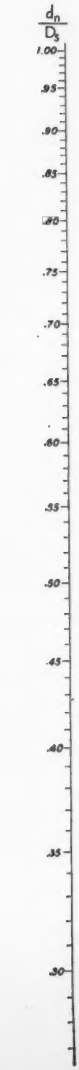
The methods of shape analysis proposed either require special apparatus not usually available or are so tedious as to discourage their use. It is the purpose of this note to recall to the attention of sedimentologists a very simple and rapid method used by Wadell (2) to determine the shapes of large rock fragments and to publish a nomograph for greatly simplifying the calculations and thus saving time.

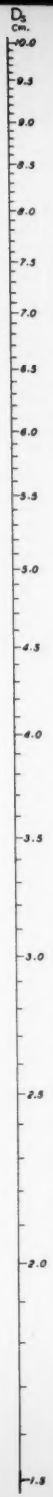
Wadell distinguished between the shape or *sphericity* (the degree to which a fragment approaches a sphere in shape) and *roundness* (the sharpness of the edges and corners). Although this distinction has been criticized (3), it is now commonly recognized as a valid distinction (4). The present note deals only with sphericity since this is probably a more significant property in transportation and deposition than roundness (5). The true sphericity, $\psi$, is defined by Wadell as $s/S$, where $s$ is the surface area of a sphere of the same volume as the pebble and $S$ is the actual surface area of the solid. Owing to difficulties of measuring the surface area of an irregular solid, Wadell proposed a "practical method" for actual analysis. In the practical formula $\Psi = d_n/D_s$, where $d_n$ is the true nominal diameter, i.e., diameter of a sphere of the same volume as the pebble and $D_s$ the diameter of a circumscribing sphere. $d_n$ is computed from a measurement of the pebble volume determined by dropping the pebble in a graduated cylinder and noting the volume of water displaced. The longest diameter of the fragment is assumed to be the diameter of the circumscribing sphere, $D_s$.[a] This may be measured by simple scale or gauge.

The computations on each pebble involve computing $d_n$ from the meas-

[a] This is not always the case as pointed out by Wadell. Exceptions are, however, believed to be too infrequent and too small to materially affect the analysis.

ALINEMENT CHART FOR COMPUTING SPHERICITY OF PEBBLES AND SMALL COBBLES





ured volume and evaluating the ratio $d_n/D_s$. The accompanying nomograph simplifies this procedure (Fig. 1). On this there are three scales marked $d_n/D_s$, Vol-$d_n$, and $D_s$. To solve the above problem, locate the volume of pebble on center scale and the maximum diameter on the $D_s$ scale. Connect these two points with straight edge. Where straight edge intersects $d_n/D_s$ scale read value of sphericity.

Allowing a minute for measurement of maximum diameter and volume, and a half minute for calculation with alinement chart, it is evident that a gravel sample of about 50–100 pebbles can be readily analyzed and that a suite of samples can be studied in the course of a few days.

The use of the alinement diagram does not reduce the accuracy of the method since errors introduced by the displacement method of volume[b] and errors made by measurement of the long diameter (to the nearest 0.1 cm) are the greater than those involved in reading the scales.[c]

Data on esker gravel, openwork glacial delta gravel, and lake beach gravel have been published.

An example of the use of the method and computation by alinement chart is here presented:

*Data concerning early pre-Cambrian conglomerate at Locality M.B. 1, Manitou Lake, Ontario.*

*Location*: Mosher Bay, Manitou Lake, District of Kenora, Ontario, Canada. About 50 chains due east of narrows between Mosher Bay and Manitou Straits on narrow neck of land separating Mosher Bay from small bay south of the same.

*Note on exposure*: Vertical conglomerate beds, strike N. 58° E., containing numerous pebbles and cobbles and a few boulders up to 20 in. in diameter. A count in one square yard disclosed 37 black cherts and iron-formation, 36 granites, 60 greenstones and metadiorites, 12 felsites and porphyries, 1 vein quartz. Bedding pronounced with pea-like grits alternating with pebble and cobble conglomerate. Pebbles readily weather out of matrix.

*Shape Analysis*: Sphericity, $\Psi = d_n/D_s$

[b] For small pebbles a small graduate (25 or 50 cc) may be used and the volume determined to within 0.5 cc. For large pebbles and cobbles, a cylinder with side spout for overflow may be used and the overflow displaced may be caught and measured with a small graduate. Determination of volume should be made to 0.5 cc. on pebbles 10 to 20 cc. in volume, to the nearest 1 cc. on pebbles 20 to 50 cc. in volume and to the nearest 2 cc. on pebbles 50 to 200 cc. in volume. This degree of accuracy will insure a sphericity value correct to the second decimal place.

[c] Wadell compared the values obtained by this method with those obtained by the formula $s/S$ and found the values of the practical method to be about 0.10 lower, on the average, than the true sphericity. He proposed to correct for this difference by adding 0.10 to all values less than 0.80. Owing to difficulties of overlapping of values in the 0.70–0.90 range, the writer does not believe such correction desirable.

| Pebble No. | Rock type | $D_s$ cm. | Vol. c.c. | $\Psi$ | Remarks |
|---|---|---|---|---|---|
| 1 | Vein quartz | 5.31 | 34 | .762 | Slightly broken |
| 2 | Felsite | 4.62 | 19 | .718 | Slightly broken |
| 3 | Greenstone | 6.31 | 29 | .604 | |
| 4 | Granite | 6.42 | 60 | .759 | A little matrix attached |
| 5 | Greenstone | 5.00 | 23 | .708 | A little matrix attached |
| 6 | Greenstone | 4.00 | 19 | .823 | |
| 7 | Felsite | 3.80 | 15 | .803 | |
| 8 | Felsite | 3.20 | 5 | .664 | |
| 9 | Granite | 8.50 | 174 | .815 | |

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# DISCUSSION

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## THE METHOD OF MOMENTS

It is gratifying to see a new statement of the method of moments in computing the constants of frequency distribution of particle sizes in sediments.[1] As Krumbein states in his paper, Wentworth described such a method several years ago,[2] though in a form somewhat different from that given by Krumbein. In reality, except for the formula for skewness, the two methods are identical and involve the same computations. Wentworth took the point of view that for the use of geologists the method should be descriptive and schematic, with a minimum use of mathematical symbols and formulae, while based on sound mathematical procedure. Whether limited use of his computing form is due to its complexity or to the difficulty of introducing mathematical procedures among geologists is a matter of opinion. Krumbein has introduced a more formal mathematical treatment; it is to be hoped that it will prove a more effective approach. In particular, Wentworth used the scale of grade sizes, which he recognized as a scale of equal geometrical, or logarithmic intervals, as if they were equal arithmetic classes, and computed a mean, or point where the first moment is zero, from the frequencies in these classes.

This is an arithmetic mean of frequencies in these classes, the limits of the classes being recognized as equal intervals on the logarithmic scale. Krumbein courageously takes the mathematical bull by the horns and converts the logarithmic scale of grade sizes into a simple scale of values of the exponent $\phi$. This symbol is the logarithm, to the base 2, of the grade limit in millimeters. From values of $\phi$, the deviations (Krumbein, Column 4, Table II) are computed. Wentworth gets the same deviations (Column 3, Fig. 4) from a starting class, by classes, these being equally logarithms to the base 2. Wentworth measures from a central, commonly modal, class arbitrarily taken for each analysis. Krumbein (page 38) has the zero of his scale of logarithms, or values of $\phi$, at one millimeter grade limit. He also uses negative logarithms which give positive values of $\phi$ for the finer sediments. Wentworth achieved the same positive and negative directions, without stating it mathematically, by giving the positive sign to the right-hand end of the grade scale as ordinarily used in plotting histograms!

In both schemes, the average computed by the first moment method is computed as an *arithmetic mean* of frequencies in classes or of logarithms of grade limits ($\phi$), but is of course a *geometric mean* of the fundamental quantities, as always achieved by taking the arithmetic mean of logarithms of numbers. The essential identity of the methods of computing the first, second and third moments will be apparent on comparing Krumbein, Table II, with Wentworth, Tables I, III, IV, and Fig. 5. Both first compute standard deviation from an arbitrarily chosen origin and correct in reference to the true mean by the well-known formula

$$\text{S.D.} = \sqrt{n_2 - (n_1)^2}$$

stated by Krumbein (page 40) and in-

[1] Krumbein, W. C., Application of Logarithmic Moments to Size Frequency Distribution of Sediments, *Jour. Sed. Petrology*, Vol. 6, 1936, pp. 35–47.

[2] Wentworth, C. K., Method of Computing Mechanical Composition Types in Sediments, *Bull. Geol. Soc. Amer.*, Vol. 40, 1929, pp. 771–790.

corporated by Wentworth in his computing form (Fig. 4). In converting class values, or $\phi$ values back to diameters of particles in millimeters, Wentworth used tables of logarithms to the base 2, with reference to the nearest class limit in millimeters, whereas Krumbein offers a conversion chart which many will regard as more convenient. As Krumbein states, various formulae are available for setting up a skewness constant from the third moment, as well as from other computed values such as quartiles. It is important to state in a given case exactly what skewness formula is used; it is impossible to say at present which will yield the most significant results in stating the asymmetries of particle size distributions.

Certain pages of Wentworth's paper carry a discussion of the relative "naturalness" of a logarithmic as compared to an arithmetic scale in answer to the misgivings of some geologists and indicate that the logarithmic scale, inherent in both schemes, is the only really practical scale for both analytic and graphic studies of sediments over a wide size range.

The continued application of statistical methods to the study of sorting of sediments is a healthy sign and it is to be hoped that the treatment by Krumbein will clarify and emphasize the advantages of the method of moments. The present discussion is intended, not at all to vindicate the Wentworth procedure but to clarify the relation of the two schemes and to suggest that for those fairly familiar with statistical procedure, one will probably prove as convenient as the other. But for others Krumbein's treatment will undoubtedly throw added light on the nature of the statistical procedure.

## REJOINDER TO WENTWORTH'S DISCUSSION OF THE METHOD OF MOMENTS

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In Wentworth's comments on his paper and mine, he stresses not only the identity of the statistical equations used in computing the moments, but also implies that step by step the procedures are identical. The agreement of equations is largely a matter of course in any moment method, inasmuch as one invariably follows conventional practice in adopting equations introduced long ago by statisticians. As for the step by step agreement of the procedures, there are, in my opinion, several points that have not been adequately stressed. These are certain fundamental differences in methods of presentation and in final results, which should be made equally explicit. Thus, during his computations, Wentworth converts the first logarithmic moment to its diameter equivalent, expressed in mm. His second moment is converted to a "size ratio deviation," and the third moment is apparently expressed directly as a logarithmic measure. This procedure results in the injection of two separate independent variables into his results, but nowhere is the distinction between them made clear.

It is here that one of the fundamental differences in viewpoint arose. My own contention is that it is quite important to maintain identity of the independent variable, so that two separate issues are not introduced into the results. This insistence on care in the choice of independent variable seems justified by the strong likelihood that if sedimentary petrologists are to escape from a purely

descriptive use of statistical measures, and to find the relations between statistical parameters and the conditions of transportation and deposition, it will be necessary to scrutinize the independent variable with some care. The point to this discussion is not that Wentworth's partial conversion to diameter equivalents is unjustified; it is merely that two independent variables unnecessarily complicate the relations between the several measures.

In addition to the differences in the treatment of the variables, is the difference in terminology of the two papers. Wentworth repeatedly uses the term "arithmetical mean" with more than an implication that he is referring to the arithmetic mean of the grain sizes, whereas his procedure, as he explains, is actually logarithmic in nature. Hence the diameter equivalent of his first moment must be the geometrical mean, although this is not mentioned. This is said in no derogatory manner; it is simply that Wentworth's caution in avoiding mathematical terminology lead to the apparent confusion of two separate issues.

It was partly because of difficulties such as these that I felt impelled to reopen the question of moment analysis The phi notation, which was developed in quite another connection,[1] was found to afford an independent variable convenient for use in sedimentary work. It was accordingly applied to the setting up of a technique of moment analysis which would make explicit the steps involved, as well as the geometrical significance of the measures derived.

Again, it is without prejudice that these points are raised. In preparing my paper, two courses were open. As between the alternatives of attacking Wentworth's terminology to effect a reconciliation of the points of view, and avoiding more than a mention of the apparent confusion of variables, the latter was chosen. I am pleased that Wentworth has explained his own use of standard statistical equations, and I join him in the hope that this clarification of the relations between the two papers may aid in a wider use of moment analysis by sedimentary petrologists.

[1] W. C. Krumbem, Size frequecy distributions of sediments: *Jour. Sed. Petrology*, vol. 4 (1934), pp. 65–77, (Appendix).

*A Study of the Sediments of the North Baltic and Adjoining Seas.* STINA GRIPENBERG, Societas Geographica Fenniae 60, No. 3, 1934. *231 pages, 28 tables, 45 figures.*

The author has undertaken a detailed and comprehensive study of the mechanical and chemical composition of the late-Glacial and post-Glacial sediments of the north Baltic and adjoining seas. The paper consists essentially of three parts: (1) Outline of chemical and mechanical technique, (2) Tabulation of results, (3) Discussion and interpretation of results.

The manner of collecting and storing the samples is briefly outlined and the methods used for the determination of carbonates, organic matter, nitrogen and electrolytes are given in some detail. The theory of the behavior of fine grained setiments in suspension is briefly stated and the pipette method, Wiegner's method and the elutriation method are described. The theory of the preliminary treatment of fine grained samples selected for mechanical analysis is outlined and the hydrogen peroxide treatment, dialysis, electrodialysis and coagulation are discussed.

The analyses reveal a marked difference in organic content between late-Glacial (1.5 per cent or less) and post-Glacial (3 or 4 per cent or more) sediments. This is thought to be due to a changed balance between inorganic and organic sedimentation, which followed the withdrawal of the ice front from a given locality. It is shown that the organic content is related to grain size, the clays as a rule containing more than the silts, and the silts more than the sands. The distribution of late-Glacial and post-Glacial sediments is described, the latter occur more commonly in depressions and in sheltered bays near land. The organic content of the post-Glacial sediments is influenced by currents. Circulation in the Baltic is described. Late-Glacial clays are uniform in organic content to a depth of 20–35 cm., whereas in post-Glacial sediments organic matter decreases with depth in the Bothnian Bay, but increases elsewhere in the Baltic. Two influences have acted upon the organic content in opposite directions, one being decrease with depth caused by time of burial and biological conditions, the other, increase due to changed conditions of sedimentation.

Nitrogen was determined in 76 bottom samples. The mean C:N ratio was found to be 10 or exactly the same as for soils. Regional differences are observable. The differences in C:N ratios is ascribed to varying influences of land humus on organic sedimentation.

The tendency to dissolve calcium carbonate, often observed in Baltic sea water, is discussed. It is shown that the surface water of the Baltic, as a rule, is unsaturated. Only in the summer is saturation possible. From the low temperatures prevailing below the discontinuity layer and the lower pH-values observed here, it may be concluded that the bottom water of the Baltic is always unsaturated with respect to calcium carbonate.

The distribution of carbonate-containing sediments over the south Bothnian Sea is described and the occurrence of Silurian limestone in this area is noted. A common feature of samples from this area, whether rich or poor in lime, is the abundant occurrence of small white lumps disseminated in the clay. The author states that these lumps are the remains of completely weathered pieces of limestone. The site and extension of the Silurian outcrop area is discussed. A low carbonate content is characteristic of samples collected near the Estonian coast in the Gulf of Finland and in the North Baltic. The lime present is attributed chiefly to the Silurian of Estonia and Gotland. No carbonates were found in samples from the Åland Sea and the Archipelago.

The mechanical composition of the Baltic bottom deposits is referred to seven different types based upon particle size and the degree of sorting. As shown by comparison with analyses of deep sea deposits determined by Odén, Trask and Stetson, the Baltic sediments belong to the finest grained type of sea deposit.

The paper is well written and should be a valuable reference for the workers who are interested in the chemical and mechanical

technique required in the study of the finer grained sediments.

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*On the Weathering of Rocks and the Composition of Clays*, ANTTI SALMINEN, Maatalouskoelaitoksen Maatutkimusosasto Agrogeologisia Julkaisuja No. 40, Soil Division of the Central Agricultural Experiment Station of Finland, Helsinki, 1935.

This bulletin presents an excellent summary and discussion of the studies made to date on the effects of weathering on the rocks of Finland. A study of the composition of clays is included with chemical analyses, many of which are recalculated to mineral composition.

The study indicates that an acid reaction of soils and ground waters exists in the northern climates, which results in the loss of alumina and iron with an increase in silica. This is contrasted with the effects of weathering of rocks in warm moist climates which give alkaline reactions; here an increase in iron and alumina with a decrease in silica is found.

Only a slight relationship exists between the composition of the bed-rock and that of the overlying clay. Salminen found that the degree of metamorphism and the age of the clay deposit have little effect on the chemical composition of the clays.

A relationship is found between the grain size and the mineralogical and chemical composition of the clay. In the finer grained sizes the percentage of bases increases and that of the silica decreases. This may be a result of the hardness of quartz relative to the other constituent minerals, and also of the different transportation capacity of the minerals. The recalculation of the chemical analyses to the mineral composition indicates an enrichment of the micas in the finer clays, accompanied by an increase in titania, alumina, and iron. The finer portions of several samples were separated in the laboratory and their analyses compared with the fine grained clays. The analyses check very closely.

A series of experiments on the effects of wave and beach action on pebbles was made and the results tabulated. Carefully weighed stones were placed on rocky and sandy beaches to determine the rate of abrasion under natural conditions. At intervals the stones were taken to the laboratory, weighed, and the loss of weight determined. A loss as large as five per cent in a month's time was found. The rate of wear was noticable in all cases, but it is more rapid on stony beaches. It is dependent upon the strength of the wave action. The ultimate product resulting from the abrasion of rocks closely corresponds to the composition of the clays studied.

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*Bordeaux et L'Estuaire Girondin*, FRANCOIS LÉVEQUE, published in Bordeaux, Imprimeries Delmas (1936), pp. 1–167.

This work is concerned with improvement of the Port of Bordeaux. The different approaches to the port are described and results of studies of the geology of the surrounding region, the passes of the Gironde River, and the coastal features and coastal sedimentation are given. The sediments contributed by the Gironde River to its estuary and the sea are described and there is consideration of the methods of the lithification of these sediments. There is considerable discussion of the differential distribution of the sediments, particularly in relation to the formation of bars. Coastal features related to erosion and the correlative deposition are described. Illustrations of ripple mark, the work of rock-boring mollusks, and the varieties of sediments are given in a number of photographs.

Several parts of the work are devoted to description of dredging and sounding apparatus and there are graphs giving the results of sounding.

While this work is primarily focused upon the engineering aspects of the approaches to the Port of Bordeaux, it contains much that is of interest to the sedimentationist.

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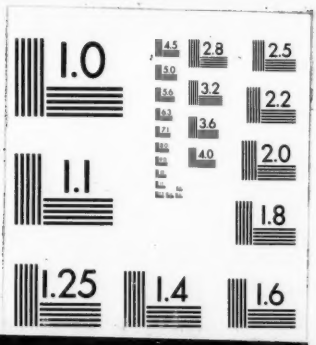
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